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TECHNICAL REPORT RG-76-56

**TRAJECTORY GENERATION BY PIECEWISE
SPLINE INTERPOLATION**

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Block 20. Abstract (Concluded)

Calculation of vehicle Euler angles is also contained as an option in the program; these are expressed as interpolating polynomial coefficients in a manner similar to that used for the trajectory. The Euler angle calculation permits the inclusion of aerodynamic angles of attack for an air-supported vehicle under the assumption that all maneuvers use coordinated turns.

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I. INTRODUCTION

In determining the performance, by simulation methods, of a missile system designed to intercept moving targets, it is frequently necessary to generate the trajectory of the targets during the course of complicated maneuvers. Various possibilities exist for expressing the target trajectories without resorting to a full numerical solution of the target dynamic equations which would require complete knowledge of all the forces acting on the target.

Target trajectories can be expressed deterministically in terms of position, velocity, or acceleration components as functions of time with respect to a particular frame of reference. It is only necessary to use one of these formulations since the others are obtainable either by integration or differentiation. Whichever form is used, an interpolation process is usually required since typical maneuvers are not expressible in terms of simple algebraic functions but must, in general, be represented as arbitrary tabulated functions of time. It is important that the interpolation process maintain mathematical continuity of at least target position and velocity since discontinuities in either of these parameters could have deleterious effects in a simulation. A typical example is the effect on simulations containing recursive target tracking filters in a digital tracking signal processor. A further requirement of the trajectory generation procedure is that it be computationally efficient with respect to computer time usage. This is an aspect of particular importance in simulations based on Monte Carlo sampling since this type tends to consume large amounts of computer time and a relatively small time reduction in each sample run can produce significant overall savings.

This report describes a method of trajectory generation which is designed to satisfy the requirements outlined in the foregoing. It is based on fitting a series of cubic splines in a piecewise manner to a set of coordinates describing the position of the target body at discrete points in time. The use of cubic splines implies that a third order polynomial is fitted between the discrete time points, and that continuity of first and second derivatives is maintained at the break-points. In this way the technique ensures continuity of position, velocity, and acceleration. Calculation of the polynomial interpolation coefficients is performed offline to the simulation and then input and stored by the simulation program. At any point in the course of the simulation the target position, velocity, and acceleration are available by the evaluation of third, second, and first order polynomials respectively, one set for each trajectory component.

This report includes a description of a computer program which performs the offline calculation of interpolation coefficients with the added facility that the input target trajectory may be specified in

terms of position, acceleration, or flight path angles at discrete time points. Target position data input is a particularly useful option when test range measured positions in an actual trajectory are required to be input; accelerations are required to be specified in a target-fixed frame based on the target velocity vector direction.

In addition to the target trajectory in terms of the kinematic parameters, it is often necessary to know the orientation of the target. This is particularly the case when detailed radar models are used which depend on target aspect angles relative to the radar antenna. The computer program contains an option to calculate the interpolation coefficients for three Euler angles in the same manner as for the trajectory position. The Euler angle representation includes the effect of target aerodynamic angle of attack, provided the requisite input data concerning target lift curve and wing loading are supplied.

II. TRAJECTORY REPRESENTATION

Output trajectories, expressed in terms of spline interpolation coefficients as functions of time, are defined relative to the Cartesian axes of an inertial frame which has its origin at a point on the earth's surface. Input data to the trajectory calculation are expressed optionally in one of three forms, two of which employ a reference frame defined by the body velocity vector. The various reference frames are described in the following paragraphs.

A. Input Reference Frame

This is an orthogonal, right-handed Cartesian frame with the origin at an arbitrary reference point on the earth's surface. The X and Y axes lie in the plane of the local horizontal, and the Z axis is along the downward vertical. Input data to the trajectory calculation which are referenced to an inertial frame use this frame. Those input data included in this classification are the position coordinates in option 1 and the initial position and velocity components of options 2 and 3 (see Section IV for descriptions of these options).

B. Output Inertial Frame

The output inertial frame is also an orthogonal, right-handed Cartesian system and is related to the input inertial frame, in general, by a translation and a rotation. The translation represents the displacement vector \underline{r}_0 of the output frame origin relative to the input frame, and the rotation is expressed in terms of three Euler angles ψ_0 , θ_0 , ϕ_0 through which the input frame rotates in order to

align itself with the output frame. The relationship of the two frames is shown in Figure 1, and the angular rotations in going from the input frame to the output frame are shown in Figure 2. In mathematical terms the transformation equation is

$$\underline{r}_{out} = [T]_{OI} (\underline{r}_{in} - \underline{r}_0) \quad (1)$$

where $[T]_{OI}$ is the matrix of direction cosines of the output frame relative to the input frame, and \underline{r}_{in} , \underline{r}_{out} are vectors expressed respectively relative to the input and output frames. Expansion of $[T]_{OI}$ into its components gives

$$\begin{aligned} T_{11} &= \cos \psi_0 \cos \theta_0 \\ T_{21} &= \cos \psi_0 \sin \theta_0 \sin \phi_0 - \sin \psi_0 \cos \phi_0 \\ T_{31} &= \cos \psi_0 \sin \theta_0 \cos \phi_0 + \sin \psi_0 \sin \phi_0 \\ T_{12} &= \sin \psi_0 \cos \theta_0 \\ T_{22} &= \cos \psi_0 \cos \phi_0 + \sin \psi_0 \sin \theta_0 \sin \phi_0 \\ T_{32} &= \sin \psi_0 \sin \theta_0 \cos \phi_0 - \cos \psi_0 \sin \phi_0 \\ T_{13} &= -\sin \theta_0 \\ T_{23} &= \cos \theta_0 \sin \phi_0 \\ T_{33} &= \cos \theta_0 \cos \phi_0 \end{aligned}$$

C. Vehicle Velocity Frame

The vehicle velocity frame is a noninertial Cartesian axis system in which the positive X_v axis is directed along the body velocity vector. The Y_v axis is directed horizontally to the right when looking from the origin along X_v , and the Z_v axis is normal to the $X_v - Y_v$ plane and thus lies in a vertical plane through the velocity vector.

In relation to the input inertial frame, the velocity frame is obtained by a rotation ψ_T about the input inertial frame Z axis, and a rotation θ_T about the new Y axis position. Origin of the velocity frame lies at the CG of the body. Figure 3 illustrates the velocity frame and its relationship to the input inertial frame.

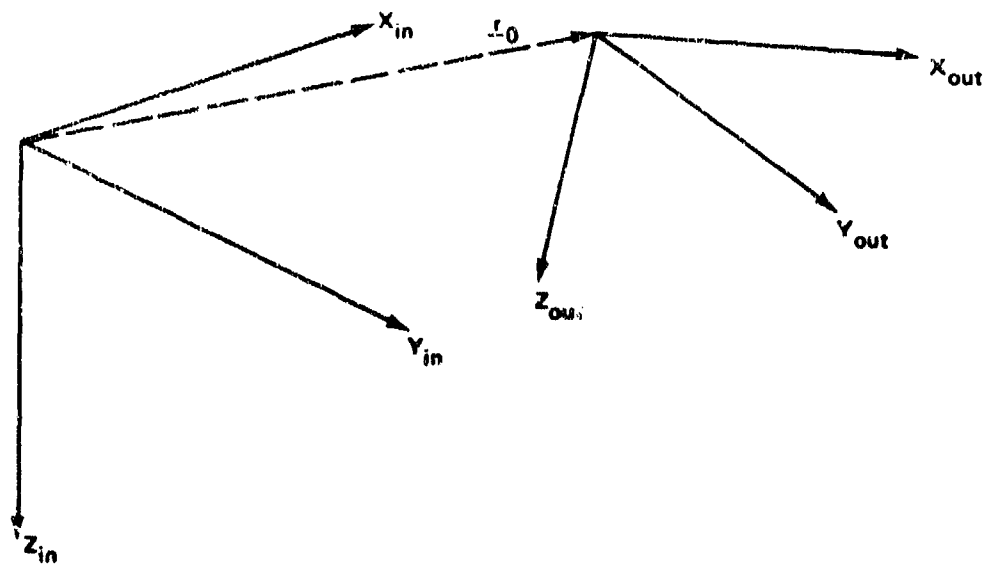


Figure 1. Input and output inertial frame.

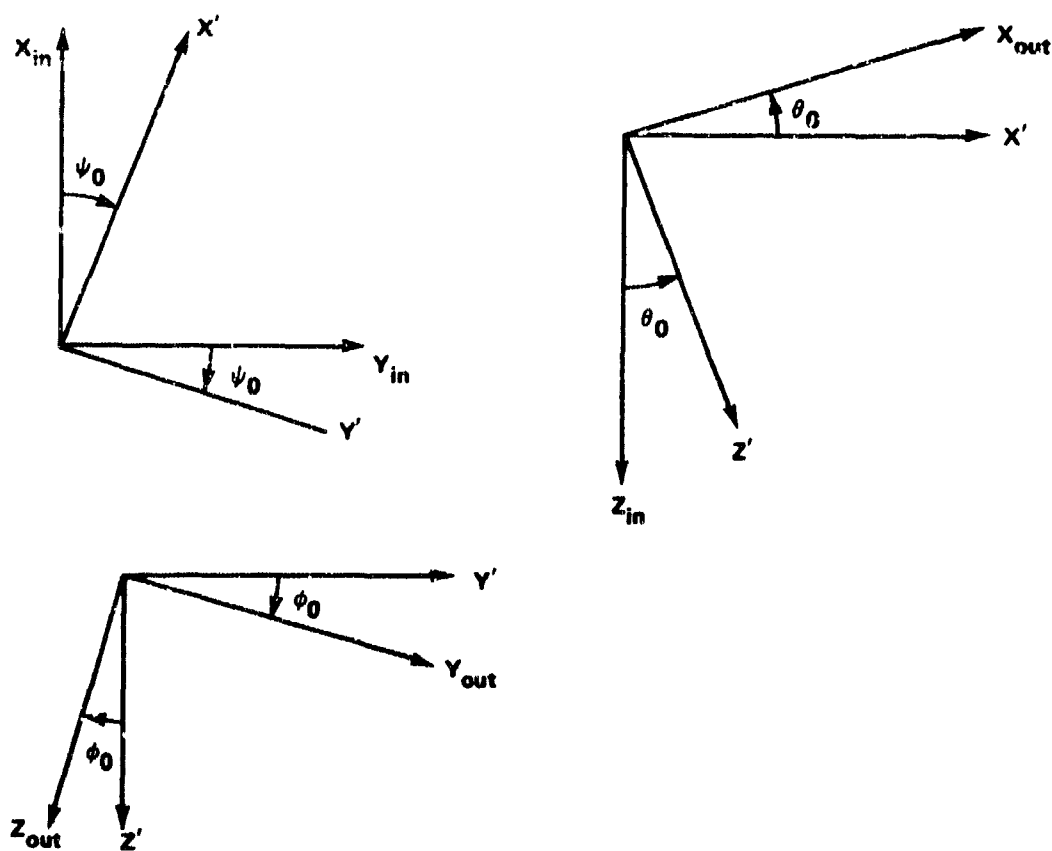


Figure 2. Input-output frame angular rotations.

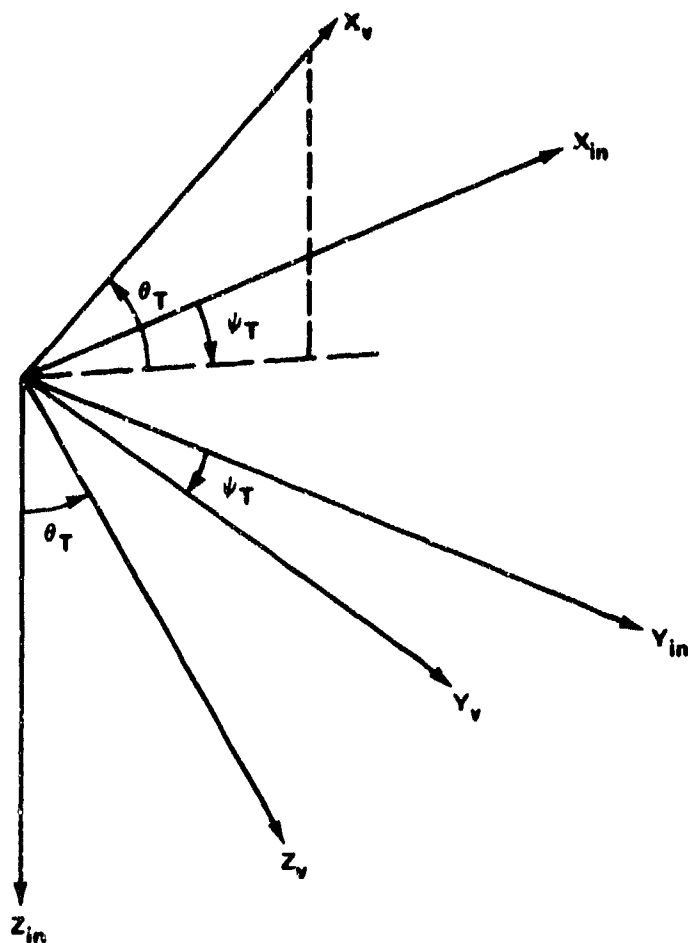


Figure 3. Orientation of velocity frame relative to input frame.

Trajectory specification options 2 and 3 express the body acceleration in this frame. Acceleration components determine the rotational rate components $\dot{\psi}_T$ and $\dot{\theta}_T$ which are integrated to give the orientation of the body velocity frame to the input inertial frame. Let the acceleration components in the velocity frame be A_{xv} , A_{yv} , A_{zv} , and let the vehicle velocity be V , then

$$\dot{V} = A_{xv} \quad (2)$$

$$\dot{\psi}_T = \frac{A_{yv}}{V \cos \theta_T} \quad (3)$$

$$\dot{\theta}_T = \frac{-A_{zv}}{V} \quad (4)$$

from which velocity components in the input inertial frame are

$$V_{XI} = V \cos \theta_T \cos \psi_T \quad (5)$$

$$V_{YI} = V \cos \theta_T \sin \psi_T \quad (6)$$

$$V_{ZI} = -V \sin \theta_T \quad (7)$$

These velocity components are integrated to yield the position of the body as a function of time from the given initial position and velocity. Initial position and velocity components are expressed relative to the input inertial frame. If the initial velocity components relative to the input frame are V_{XIC} , V_{YIC} , V_{ZIC} , then

$$\psi_{TIC} = \tan^{-1} \left(\frac{V_{YIC}}{V_{XIC}} \right) \quad (8)$$

and

$$\theta_{TIC} = \sin^{-1} \left\{ \frac{-V_{ZIC}}{\sqrt{V_{XIC}^2 + V_{YIC}^2 + V_{ZIC}^2}} \right\} \quad (9)$$

III. CUBIC SPLINE INTERPOLATION

This section contains a brief outline of the underlying theory of curve fitting by means of cubic splines. A more detailed analysis is given by Schultz.¹

¹Schultz, Martin H., Spline Analysis, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1973.

The fitting of smooth curves to function values given at discrete intervals of an independent variable has received considerable attention in the past. A well-known procedure is that due to Lagrange in which an N^{th} order polynomial is fitted to $N + 1$ function values. However, it is also well-known that for values of N of moderate size and larger, the procedure can diverge and produce highly unsatisfactory results.²

The modern approach to curve fitting has received much impetus from finite element techniques and has led to the use of piecewise polynomial fitting with constraints on the derivatives at the end points of each interval. A requirement for continuity of first derivatives at the interval end points yields a set of interpolating polynomials which are "local" in the sense that each polynomial depends only on the independent variable and function values at the end points of each interval. As such, it is an extension of the method of piecewise linear interpolation which is in common use. This technique, using cubic polynomials, is described as follows. It should be noted that although cubic polynomials are often used, the procedure can readily be generalized to higher order polynomials.

Consider a set of $N + 2$ real numbers $x_0 < x_1 < x_2 < \dots < x_{N+1}$ and an associated set of function values $\{f_i, f'_i\}$ $i = 0, 1, 2, \dots, N + 1$ where the prime superscript implies differentiation with respect to x . Let $p(x)$ be a cubic polynomial such that $p(x_i) = f_i$, $p(x_{i+1}) = f_{i+1}$, $dp(x_i)/dx = f'_i$ and $dp(x_{i+1})/dx = f'_{i+1}$. Also let the interpolated value of f be F ; then F may be expressed as

$$F = \sum_{i=0}^{N+1} (f_i h_i(x) + f'_i h'_i(x)) \quad (10)$$

where $h_i(x)$ and $h'_i(x)$ are "basis" functions of x with the following properties:

$$h_i(x_j) = \delta_{ij} \quad 0 \leq i, j \leq N + 1 \quad (11)$$

²Hamming, Richard W., Introduction to Applied Numerical Analysis, McGraw-Hill Book Company, New York, 1971, pp. 146-163.

$$h'_i(x_j) = 0 \quad (12)$$

$$\frac{d}{dx} h'_i(x_j) = \delta_{ij} \quad (13)$$

δ_{ij} is the Kronecker delta function. For $i = 1, 2, 3, \dots, N$

$$h_i(x) = \begin{cases} \frac{(x - x_{i-1})^2}{(x_i - x_{i-1})^2} \left\{ 3 - \frac{2(x - x_{i-1})}{(x_i - x_{i-1})} \right\} & x_{i-1} \leq x \leq x_i \\ \frac{(x - x_i)^2}{(x_{i+1} - x_i)^2} \left\{ \frac{2(x - x_i)}{(x_{i+1} - x_i)} - 3 \right\} + 1 & x_i < x < x_{i+1} \\ 0 & x \leq x_{i-1}, x \geq x_{i+1} \end{cases} \quad (14)$$

$$h'_i(x) = \begin{cases} \frac{(x - x_i)(x - x_{i-1})^2}{(x_i - x_{i-1})^2} & x_{i-1} \leq x \leq x_i \\ \frac{(x - x_i)(x_{i+1} - x)^2}{(x_{i+1} - x_i)^2} & x_i \leq x \leq x_{i+1} \\ 0 & x \leq x_{i-1}, x \geq x_{i+1} \end{cases} \quad (15)$$

For $i = 0$

$$h_0(x) = \begin{cases} \frac{(x - x_0)^2}{(x_1 - x_0)^2} \left\{ \frac{2(x - x_0)}{(x_1 - x_0)} - 3 \right\} + 1 & x_0 \leq x \leq x_1 \\ 0 & x_1 \leq x \leq x_N + 1 \end{cases} \quad (16)$$

$$h'_0(x) = \begin{cases} \frac{(x - x_0)(x_1 - x)^2}{(x_1 - x_0)^2} & x_0 \leq x \leq x_1 \\ 0 & x_1 \leq x \leq x_{N+1} \end{cases} \quad (17)$$

and for $i = N + 1$

$$h'_{N+1}(x) = \begin{cases} \frac{(x - x_N)^2}{(x_{N+1} - x_N)^2} \left(3 - \frac{2(x - x_N)}{x_{N+1} - x_N} \right) & x_N \leq x \leq x_{N+1} \\ 0 & 0 \leq x \leq x_N \end{cases} \quad (18)$$

$$h'_{N+1}(x) = \begin{cases} \frac{(x - x_N)^2 (x - x_{N+1})}{(x_{N+1} - x_N)^2} & x_N \leq x \leq x_{N+1} \\ 0 & 0 \leq x \leq x_N \end{cases} \quad (19)$$

Expanding Equation (10) for the case of $x_1 \leq x \leq x_1 + 1$ gives

$$F = f_1 + \frac{(f_{1+1} - f_1)(x - x_1)^2}{(x_1 + 1 - x_1)^2} \left\{ 3 - \frac{2(x - x_1)}{(x_1 + 1 - x_1)} \right\} + \frac{(x - x_1)}{(x_1 + 1 - x_1)^2} \left\{ f'_1(x_1 + 1 - x)^2 + f'_{1+1}(x - x_1)(x - x_1 + 1) \right\}. \quad (20)$$

If a piecewise independent variable is written Δx , where $\Delta x = x - x_1$, then a piecewise cubic polynomial may be defined for $x_1 \leq x \leq x_1 + 1$ as

$$p(\Delta x)_i = a_0 + a_1 \Delta x + a_2 \Delta x^2 + a_3 \Delta x^3, \quad (21)$$

and the coefficients are obtained from Equation (20) as

$$a_0 = f_i \quad (22)$$

$$a_1 = f'_i \quad (23)$$

$$a_2 = \frac{3(f_{i+1} - f_i)}{(x_{i+1} - x_i)^2} - \frac{2f'_i + f'_{i+1}}{x_{i+1} - x_i} \quad (24)$$

$$a_3 = \frac{-2(f_{i+1} - f_i)}{(x_{i+1} - x_i)^3} + \frac{f'_i + f'_{i+1}}{(x_{i+1} - x_i)^2} \quad (25)$$

In many cases the derivatives f'_i of the function f are not available and it becomes necessary to approximate them from values of f_i .

A method of performing this approximation is to use local cubic Lagrange interpolation polynomials to fit a curve through groups of four points and obtain f'_i from these polynomials. The procedure is described as follows. Let the Lagrange polynomials be $r_k(x)$ defined by

$$r_k(x) = \sum_{i=0}^3 \eta_{k,i}(x) f_{k+i} \quad (\text{for } N \geq 2) \quad (26)$$

where

$$\eta_{k,i}(x) = \frac{\prod_{\substack{j=0 \\ j \neq i}}^3 (x - x_{k+j})}{\prod_{\substack{j=0 \\ j \neq i}}^3 (x_{k+1} - x_{k+j})} \quad (27)$$

which interpolates f_{k+1} for $i = 0, 1, 2, 3$. Derivatives of f may then be approximated as follows:

$$f'_i = \frac{df(x_i)}{dx} = \begin{cases} \frac{d}{dx} (r_i(x_i)) & i = 0 \\ \frac{d}{dx} (r_{i-1}(x_i)) & i = 1 \\ \frac{1}{2} \left\{ \frac{d}{dx} (r_{i-2}(x_i)) + \frac{d}{dx} (r_{i-1}(x_i)) \right\} & 2 \leq i \leq N-1 \\ \frac{d}{dx} (r_{i-2}(x_i)) & i = N \\ \frac{d}{dx} (r_{i-3}(x_i)) & i = N+1 \end{cases} \quad (28)$$

The term "spline interpolation" implies the fitting of polynomials in a piecewise manner as described but with the added constraint that second and higher derivatives of the function are given continuity at the interval end points, thus simulating the effect of forcing a thin, flexible spline to pass through the function points. The physical process of clamping a spline to a certain number of function values is one that is commonly used in naval architecture and ship design. For the purposes of this report, the spline functions considered will be restricted to cubic polynomials and only second derivatives will be equated at interval end points. The general case of k^{th} order polynomials used is often referred to as B-spline fitting.

To illustrate the cubic spline interpolation process, consider again the set of function values f_i corresponding to a set of independent variable breakpoints x_i , $i = 0, 1, 2, \dots, N+1$. Let $p(x)$ be the cubic interpolating polynomial for the interval $x_{i-1} \leq x \leq x_i$ and let $q(x)$ be the cubic interpolating polynomial for the interval $x_i \leq x \leq x_{i+1}$ with the following properties for $1 \leq i \leq N$

$$p(x_i) = q(x_i) = f_i \quad (29)$$

$$\frac{d}{dx} p(x_1) = \frac{d}{dx} q(x_1) = f'_1 \quad (30)$$

Using Equation (20), the polynomials $p(x)$ and $q(x)$ may be expanded about the point x_1 to give

$$\begin{aligned} p(x) = & p(x_1) + Dp(x_1)(x - x_1) + \left\{ \frac{3}{\Delta x_1 - 1} [p(x_1 - 1) - p(x_1)] \right. \\ & + Dp(x_1 - 1) + 2Dp(x_1) \left. \right\} \frac{(x - x_1)^2}{\Delta x_1 - 1} \\ & + \left\{ \frac{2}{\Delta x_1 - 1} [p(x_1 - 1) - p(x_1)] + Dp(x_1 - 1) \right. \\ & + Dp(x_1) \left. \right\} \frac{(x - x_1)^3}{\Delta x_1^2 - 1} \end{aligned} \quad (31)$$

$$\begin{aligned} q(x) = & q(x_1) + Dq(x_1)(x - x_1) + \left\{ \frac{3}{\Delta x_1} [q(x_1 + 1) - q(x_1)] \right. \\ & + Dq(x_1 + 1) + 2Dq(x_1) \left. \right\} \frac{(x - x_1)^2}{\Delta x_1} \\ & + \left\{ \frac{2}{\Delta x_1} [q(x_1 + 1) - q(x_1)] + Dq(x_1 + 1) \right. \\ & + 2Dq(x_1) \left. \right\} \frac{(x - x_1)^3}{\Delta x_1^2} \end{aligned} \quad (32)$$

where

$$D^n = \frac{d^n}{dx^n}$$

$$\Delta x_1 - 1 = x_1 - x_1 - 1$$

$$\Delta x_1 = x_1 + 1 - x_1$$

The requirement for continuity of second derivatives at the point x_1 is

$$D^2 p(x_1) = D^2 q(x_1) \quad (33)$$

and by analogy with the Taylor Series expansion about x_1 , then

$$D^2 p(x_1) = \frac{2}{\Delta x_1 - 1} \left\{ \frac{3}{\Delta x_1 - 1} [p(x_1 - 1) - p(x_1)] \right. \\ \left. + Dp(x_1 - 1) + 2Dp(x_1) \right\} \quad (34)$$

$$D^2 q(x_1) = \frac{2}{\Delta x_1} \left\{ \frac{3}{\Delta x_1} [q(x_1 + 1) - q(x_1)] \right. \\ \left. + Dq(x_1 - 1) + 2Dq(x_1) \right\} \quad (35)$$

which leads to the requirement

$$\Delta x_1 f'_1 - 1 + 2f'_1 (\Delta x_1 + \Delta x_1 - 1) + \Delta x_1 - 1 f'_1 + 1 \\ = 3 \left\{ \frac{\Delta x_1 - 1}{\Delta x_1} (f_{i+1} - f_i) \right. \\ \left. + \frac{\Delta x_1}{\Delta x_1 - 1} (f_i - f_{i-1}) \right\} \quad 1 \leq i \leq N \quad (36)$$

Equation (36) represents a set of N linear equations in f'_1 which may be written in vector form as

$$[B_{ij}] \underline{f}' = \underline{c} \quad 1 \leq i, j \leq N \quad (37)$$

where the matrix $[B_{ij}]$ is given by

$$B_{ij} = \begin{cases} 2(\Delta x_i + \Delta_i - 1) & 1 \leq i = j \leq N \\ \Delta x_i & 1 \leq j = i - 1 \leq N - 1 \\ \Delta x_i - 1 & 2 \leq j = i + 1 \leq N \\ 0 & \text{otherwise} \end{cases} \quad (38)$$

and the vector \underline{c} is given by

$$c_i = \begin{cases} 3 \left[\frac{\Delta x_0 \Delta f_1}{\Delta x_1} + \frac{\Delta x_1 \Delta f_0}{\Delta x_0} \right] - \Delta x_1 f'_0 & i = 1 \\ 3 \left[\frac{\Delta x_{i-1} \Delta f_i}{\Delta x_i} + \frac{\Delta x_i \Delta f_{i-1}}{\Delta x_{i-1}} \right] & 1 < i < N \\ 3 \left[\frac{\Delta x_{N-1} \Delta f_N}{\Delta x_N} + \frac{\Delta x_N \Delta f_{N-1}}{\Delta x_{N-1}} \right] - \Delta x_{N-1} f'_{N+1} & i = N \end{cases} \quad (39)$$

where

$$\Delta f_i = f_{i+1} - f_i$$

$$\Delta f_{i-1} = f_i - f_{i-1}$$

As can be observed from definition Equation (38), the matrix B_{ij} is tridiagonal and it can be shown³ that the system of Equations (37) has a unique solution; in fact, Equations (37) can be readily solved by Gaussian elimination.

Interpolated function values are then obtained by substituting in Equation (10), yielding the interpolant F as

$$F = \sum_{i=0}^{N+1} f_i h_i(x) + f'_0 h'_0(x) + \sum_{i=1}^N f'_i h'_i(x) + f'_{N+1} h'_{N+1}(x) \quad (40)$$

³Schultz, loc. cit.

where f'_i ($i = 1, 2, \dots, N$) have been obtained from the solution of Equations (37). Note that F is no longer a "local" interpolating function since all f_i are used in obtaining f'_i . Piecewise polynomial interpolation coefficients are given by Equations (22) through (25).

It remains only to choose a method of calculating the extremity derivatives f'_0 and f'_{N+1} . These derivatives may be obtained from local cubic Lagrange polynomials at $k = 0$ and $k = N - 2$ as given in Equations (17) and (18), i.e.,

$$r_0(x) = \sum_{i=0}^3 \eta_{0,i}(x) f_i \quad (41)$$

$$r_{N-2}(x) = \sum_{i=0}^3 \eta_{N-2,i}(x) f_{N-2+i} \quad (42)$$

and the derivatives f'_0 and f'_{N+1} are approximated as

$$f'_0 = Dr_0(x_0) \quad (43)$$

$$f'_{N+1} = Dr_{N-2}(x_{N+1}) \quad (44)$$

An example of cubic spline curve fitting is contained in Figure 4, in which function values are indicated at the appropriate breakpoints in x , and the full line is that obtained by the spline interpolation process.

IV. TRAJECTORY GENERATION

The input data to the trajectory generation program may be specified in one of three ways, chosen at the option of the user. These options are described in the following paragraphs. All three options require that the origin translation and frame rotation of the output frame relative to the input frame be specified. For options 2 and 3, initial body position and velocity relative to the input frame must be included in the data.

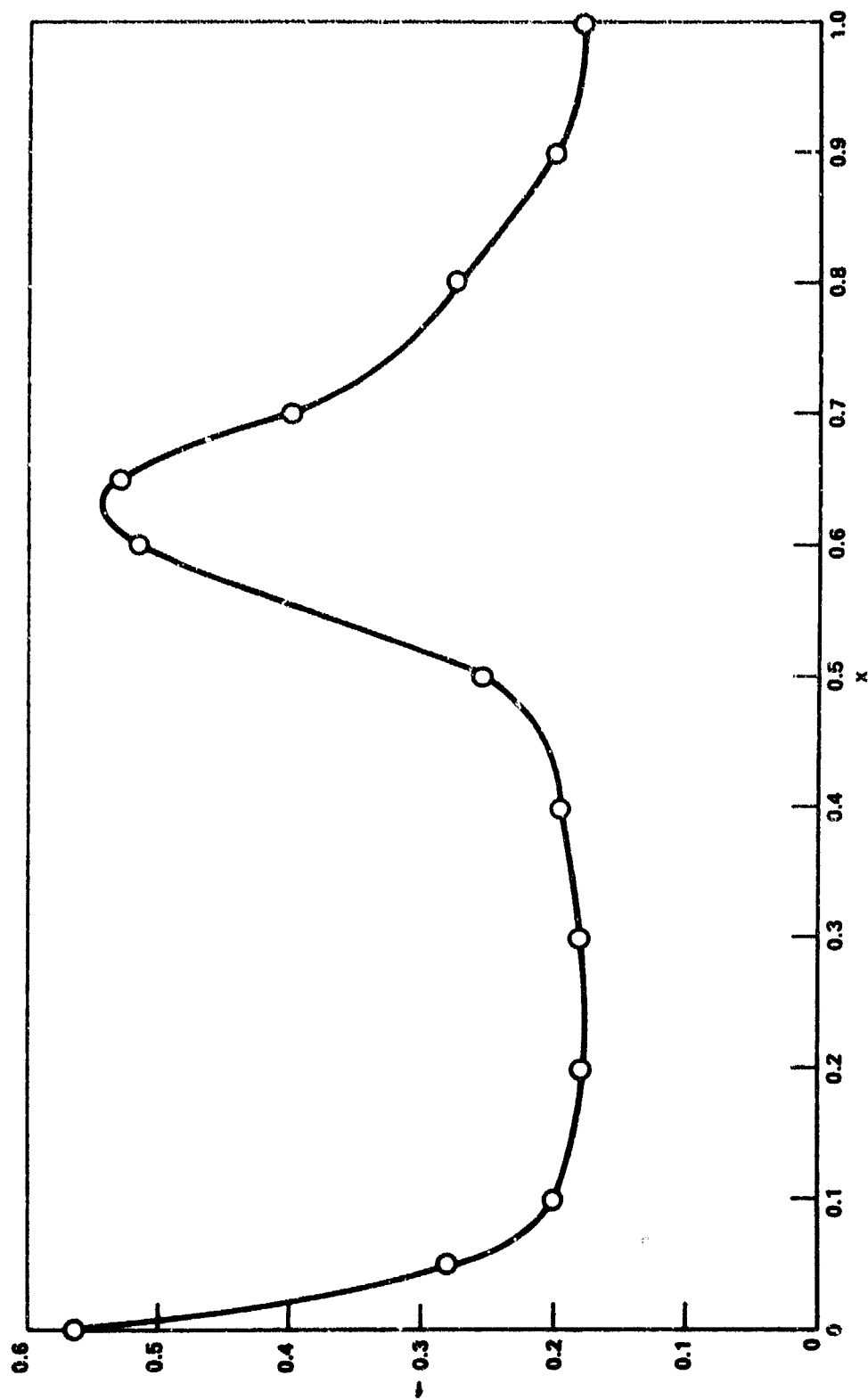


Figure 4. Cubic spline interpolation example.

A. Option 1 - Position Input

For this case the input data consists of sets of values of body position coordinates relative to the input reference frame and an associated value of time. Data sets should cover the time span of the trajectory at intervals demanded by the rates of change of trajectory parameters.

B. Option 2 - Acceleration Input

Applied acceleration components in the body velocity frame are specified as arbitrary functions of time over the required time span of the trajectory. The acceleration functions are required to be specified in units of local gravitational acceleration, and the local gravity is related to sea level gravity (assuming a spherical earth) by

$$g = g_0 \left(\frac{R_0}{R_0 + H} \right)^2 \quad (45)$$

$$H = \sqrt{X_I^2 + Y_I^2 + (R_0 - Z_I)^2} - R_0 \quad (46)$$

where g_0 is mean sea-level gravity acceleration, R_0 is the mean radius of the earth, X_I , Y_I , Z_I are body coordinates relative to the input reference frame, and H is the body altitude above the earth's surface. Derivation of Equation (46) is readily apparent from Figure 5.

The body trajectory is obtained by integrating the kinematic equations to give position coordinates, as indicated by Equations (2) through (7). Acceleration functions are assumed to be continuous between the specified data points; linear interpolation in the functions is used to obtain intermediate acceleration values.

C. Option 3 - Flight Path Angle Input

For option 3 input data are specified by expressing flight path angles ψ_T and θ_T as arbitrary functions of time, together with the longitudinal acceleration in the velocity frame as a function of time. The changes in flight path angles between consecutive pairs of time breakpoints are converted to equivalent accelerations and the body trajectory is obtained as in option 2. For this case, however, the acceleration is assumed to be constant between adjacent pairs of time breakpoints, and to change discontinuously at each breakpoint.

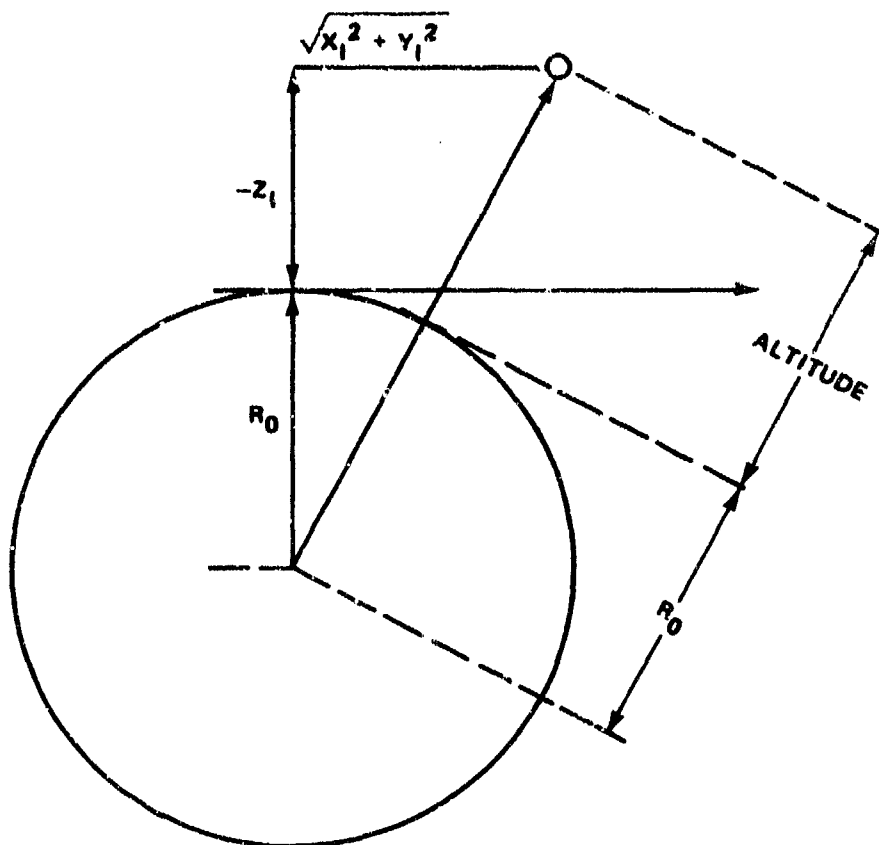


Figure 5. Vehicle altitude above earth's surface.

D. Trajectory Interpolation

Program output consists of sets of polynomial coefficients at discrete time points contained within the input data. The polynomial coefficients generate the vehicle position as a function of time in the following manner. Let t be the current time and let the discrete time breakpoints be $t_0 < t_1 < t_2 \dots < t_N$, and let $\Delta t = t - t_1$ for some $0 \leq i < N$ where $t_1 < t < t_{i+1}$, then

$$X_0 = a_0 + a_1 \Delta t + a_2 \Delta t^2 + a_3 \Delta t^3 \quad (47)$$

where X_0 is the X coordinate of vehicle position relative to the output reference frame and a_0, a_1, a_2, a_3 are the polynomial coefficients for the X coordinate within the time interval t_1 to t_{i+1} . Coordinates

Y and Z are generated by similar sets of coefficients. Coefficients are calculated for time intervals from t_0 to t_N ; thus there are N sets of coefficients for the $N + 1$ breakpoints.

Velocity and acceleration components are generated by differentiation, i.e.,

$$V_{x0} = a_1 + 2a_2\Delta t + 3a_3\Delta t^2 \quad (48)$$

$$A_{x0} = 2a_2 + 6a_3\Delta t \quad (49)$$

From the above it can be seen that the interpolation process consists simply of determining i for a given value of t and evaluating Equations (47), (48), and (49) to obtain the vehicle trajectory. In simulation applications t is inevitably monotonically increasing, which makes the determination of i a simple matter and avoids extensive searching of the table of time breakpoints.

V. VEHICLE EULERIAN ANGLES

The Euler angles of the vehicle with respect to the output reference frame are expressed in the same form as the final output trajectory, i.e., as sets of spline interpolation coefficients at discrete intervals in time. An option in the calculation permits the inclusion of aerodynamic angles of attack under the assumption that the vehicle is air-supported by fixed wings and that all maneuvering turns are coordinated. That is, the body sideslip angle is always zero.

Euler angles of the vehicle with respect to the output reference frame are defined by three rotations required to align the output frame with a vehicle-fixed frame. The rotations are ψ_B about the Z_{out} axis, θ_B about the resultant position of the Y_{out} axis, and ϕ_B about the vehicle X axis.

The vehicle velocity frame relative to the output reference frame has angles ψ_{T0} and θ_{T0} defined similarly to ψ_T and θ_T for the input frame. However, ψ_{T0} and θ_{T0} are calculated from velocity components relative to the output reference frame obtained by differentiating the cubic spline representation of the trajectory, as indicated in Section IV. If the vehicle velocity components relative to the output frame are V_{x0} , V_{y0} , V_{z0} , then

$$\psi_{T0} = \tan^{-1} \left(\frac{v_{y0}}{v_{x0}} \right) \quad (50)$$

$$\theta_{T0} = \sin^{-1} \left\{ \frac{-v_{z0}}{\sqrt{v_{x0}^2 + v_{y0}^2 + v_{z0}^2}} \right\} \quad (51)$$

To perform a coordinated turn, a roll angle about the velocity vector is required in order to maintain a balance of forces, as indicated in Figure 6 which shows that the lift generated normal to the velocity vector must provide the force to support the body and provide the forces to produce the lateral accelerations. It is assumed that acceleration along the velocity vector is produced by external forces such as engine thrust and aerodynamic drag. The gravitational acceleration acts along the Z_{in} axis and, therefore, transforming to the output frame the gravitational acceleration is

$$\underline{g}_0 = [T]_{OI} \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} \quad (52)$$

which expands to

$$g_{x0} = -g \sin \theta_0 \quad (53)$$

$$g_{y0} = g \cos \theta_0 \sin \phi_0 \quad (54)$$

$$g_{z0} = g \cos \theta_0 \cos \phi_0 \quad (55)$$

The body acceleration, represented by the trajectory interpolation coefficients, is \underline{A}_0 relative to the output frame. For the force balance of Figure 6, this must be transformed to the body velocity frame through the angles ψ_{T0} and θ_{T0} . The lateral acceleration terms in the velocity frame are thus

$$A_{yv0} = -A_{x0} \sin \psi_{T0} + A_{y0} \cos \psi_{T0} \quad (56)$$

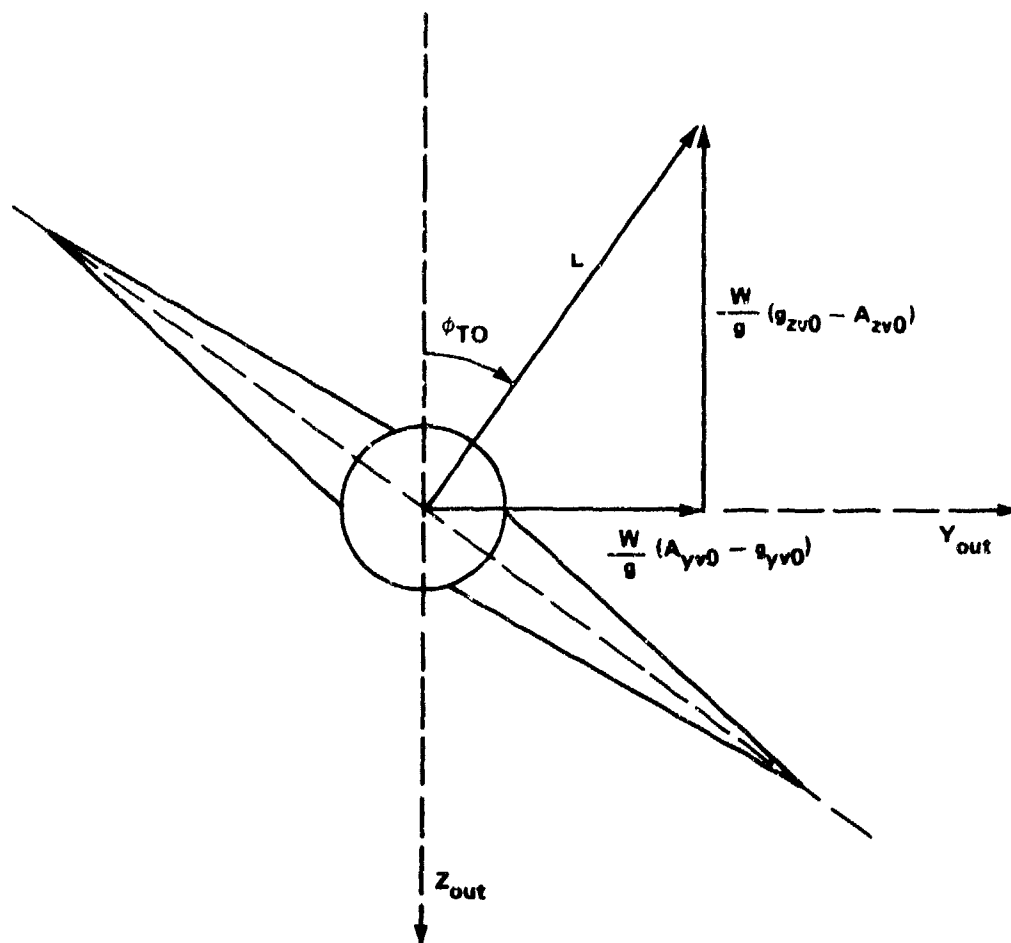


Figure 6. Vehicle lateral force balance.

$$A_{zv0} = A_{x0} \cos \psi_{T0} \sin \theta_{T0} + A_{y0} \sin \psi_{T0} \sin \theta_{T0} + A_{z0} \cos \theta_{T0} \quad (57)$$

and the gravitational acceleration transformed to the body frame is, in the lateral directions

$$g_{yv0} = -g_{x0} \sin \psi_{T0} + g_{y0} \cos \psi_{T0} \quad (58)$$

$$g_{zv0} = g_{x0} \cos \psi_{T0} \sin \theta_{T0} + g_{y0} \sin \psi_{T0} \sin \theta_{T0} + g_{z0} \cos \theta_{T0} \quad (59)$$

where A_{x0} , A_{y0} , A_{z0} are components of \underline{A}_0 in the output frame. The vehicle lift force L must provide a component along Z_v , which has a resultant acceleration of A_{zv0} and a horizontal component which has a resultant acceleration of A_{yv0} with L acting normal to the vehicle wingspan and velocity vector. Thus, the vehicle bank angle is given by

$$\phi_{T0} = \tan^{-1} \left(\frac{A_{yv0} - g_{yv0}}{g_{zv0} - A_{zv0}} \right) \quad (60)$$

and the lift force L is given by

$$L = \frac{W}{g} \sqrt{(A_{yv0} - g_{yv0})^2 + (g_{zv0} - A_{zv0})^2}, \quad (61)$$

where W is the vehicle weight. Note that in Equation (60) if both numerator and denominator are zero, ϕ_{T0} is undefined since this would be the case of the body falling freely under gravity. A further point to be carefully considered concerns the definition of the vehicle velocity frame. If $\theta_0 \neq 0$ or $\phi_0 \neq 0$, then the velocity frames obtained by rotating ψ_T , θ_T from the input reference frame and ψ_{T0} , θ_{T0} from the output reference frame will differ by an apparent roll angle, as can be deduced from Equation (58) in which the Y_v axis has a gravitational component acting along it. For this reason the acceleration components A_{yv0} and A_{zv0} are, in general, not equal respectively to A_{yv} and A_{zv} of Section II.

If it is assumed that the lift curve for the vehicle can be approximated by the form given in Figure 7 and is an odd function about $\alpha = 0$, the angle of attack can be approximated by first calculating the vehicle lift coefficient as

$$C_L = \frac{\frac{W}{S} \sqrt{\left(\frac{A_{yv0} - g_{yv0}}{g} \right)^2 + \left(\frac{g_{zv0} - A_{zv0}}{g} \right)^2}}{\frac{1}{2} \rho v^2} \quad (62)$$

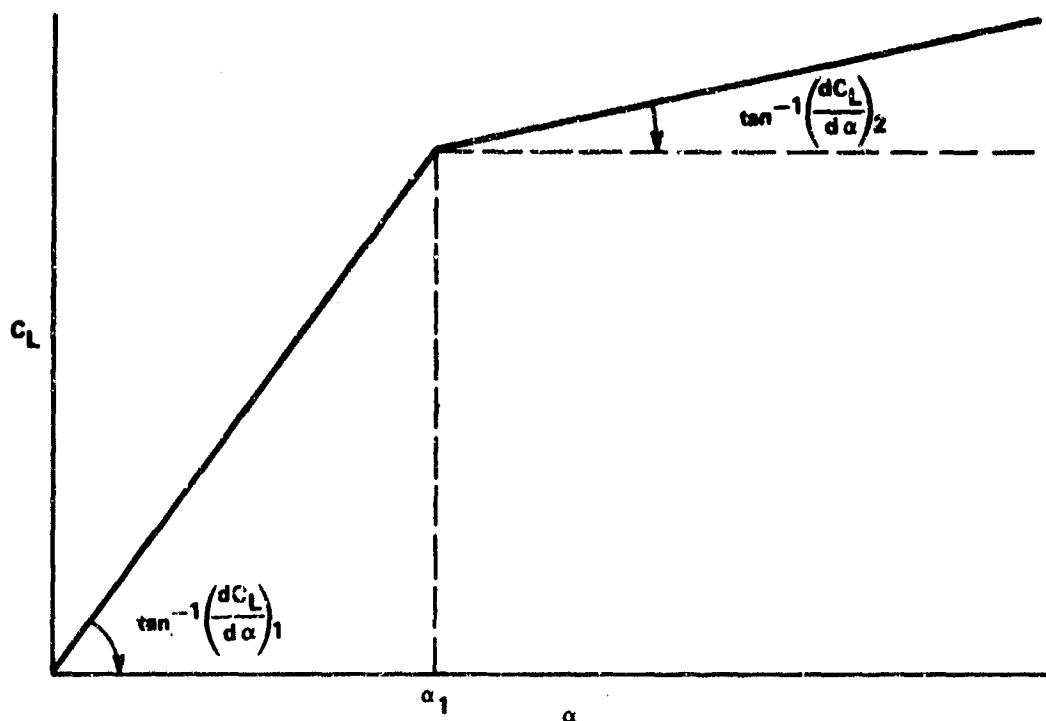


Figure 7. Idealized lift curve slope.

where W/S is the vehicle wing loading, ρ is the ambient air density, and V is the vehicle total speed. The angle of attack is then

$$\alpha = \begin{cases} \frac{C_L}{\left(\frac{dC_L}{d\alpha}\right)_1} & \alpha \leq \alpha_1 \\ \alpha_1 + \frac{C_L - \alpha_1 \left(\frac{dC_L}{d\alpha}\right)_1}{\left(\frac{dC_L}{d\alpha}\right)_2} & \alpha \geq \alpha_1 \end{cases} \quad (63)$$

ρ is a function of vehicle altitude H , where H is given by Equation (46) in which X_I , Y_I , Z_I are referenced to the input frame. Thus, for position coordinates referenced to the output frame, H must be determined by a transformation of the trajectory coordinates to the input reference frame. Lift curve parameters α_1 , $(dC_L/d\alpha)_1$, and $(dC_L/d\alpha)_2$

are illustrated in Figure 7. Note that α as defined by Equation (63) is always positive. A set of rotations from the output reference frame to the vehicle fixed frame is ψ_{T0} , θ_{T0} , ϕ_{T0} , α_{T0} where

$$\alpha_{T0} = \begin{cases} \alpha & \text{if } (g_{zv0} - A_{zv0}) \geq 0 \\ -\alpha & \text{if } (g_{zv0} - A_{zv0}) < 0 \end{cases} \quad (64)$$

These rotations may be expressed as a set of matrix products to form a transformation matrix of direction cosines which rotates the output reference frame to the vehicle fixed frame as follows:

$$[T]_{V0} = [t_\alpha][t_\phi][t_\theta][t_\psi] \quad (65)$$

where

$$[t_\alpha] = \begin{bmatrix} \cos \alpha_{T0} & 0 & -\sin \alpha_{T0} \\ 0 & 1 & 0 \\ \sin \alpha_{T0} & 0 & \cos \alpha_{T0} \end{bmatrix} \quad (66)$$

$$[t_\phi] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \phi_{T0} & \sin \phi_{T0} \\ 0 & -\sin \phi_{T0} & \cos \phi_{T0} \end{bmatrix} \quad (67)$$

$$[t_\theta] = \begin{bmatrix} \cos \theta_{T0} & 0 & -\sin \theta_{T0} \\ 0 & 1 & 0 \\ \sin \theta_{T0} & 0 & \cos \theta_{T0} \end{bmatrix} \quad (68)$$

$$[t_\psi] = \begin{bmatrix} \cos \psi_{T0} & \sin \psi_{T0} & 0 \\ -\sin \psi_{T0} & \cos \psi_{T0} & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (69)$$

The transformation matrix $[T]_{V0}$ is equivalent to a matrix of direction cosines formed from the Euler angles ψ_B , θ_B , and ϕ_B . The direction cosine matrix contains elements of the same form as that given for the expansion of $[T]_{OI}$ (Paragraph II.B) with ψ_B , θ_B , ϕ_B substituted for ψ_0 , θ_0 , ϕ_0 . By inspection of the terms in the expansion of $[T]_{OI}$, the Euler angles are given by

$$\psi_B = \tan^{-1} \left(\frac{t_{12}}{t_{11}} \right) \quad (70)$$

$$\theta_B = \sin^{-1} (-t_{13}) \quad (71)$$

$$\phi_B = \tan^{-1} \left(\frac{t_{23}}{t_{33}} \right) \quad (72)$$

where t_{12} , t_{13} , t_{23} , t_{33} are elements of the matrix $[T]_{V0}$. Evaluating these terms from Equations (66) through (69), the vehicle Euler angles are

$$\psi_B = \tan^{-1} \left(\frac{\cos \theta_{T0} \sin \psi_{T0} \cos \alpha_{T0} - \sin \theta_{T0} \cos \psi_{T0} \cos \phi_{T0} \sin \alpha_{T0}}{\cos \theta_{T0} \cos \psi_{T0} \cos \alpha_{T0} - \sin \psi_{T0} \sin \phi_{T0} \sin \alpha_{T0}} \right) \quad (73)$$

$$\theta_B = \sin^{-1} (\sin \theta_{T0} \cos \alpha_{T0} + \cos \theta_{T0} \cos \phi_{T0} \sin \alpha_{T0}) \quad (74)$$

$$\phi_B = \tan^{-1} \left(\frac{\cos \theta_{T0} \sin \phi_{T0}}{\cos \theta_{T0} \cos \phi_{T0} \cos \alpha_{T0} - \sin \theta_{T0} \sin \alpha_{T0}} \right) \quad (75)$$

It should be noted that if the vehicle angle of attack is negligible, then Euler angles are easily deducible from the trajectory interpolation coefficients via the first and second derivatives of the interpolating polynomial and Equations (50), (51), and (60). In this case the calculation of Euler angle interpolation coefficients is unnecessary.

A further consideration in the calculation of polynomial interpolation coefficients for the Euler angles concerns the range of values taken by the Euler angles themselves. Equations (73) and (75) normally yield principal values of the angles, i.e., in the range $\pm\pi$.

Thus, when the angles pass from a value close to π to one close to $-\pi$ the spline fitting process will assume that the angle has passed through zero giving rise to incorrect results. To counteract this effect, the range of values taken by the angle must be extended by converting the principal values to 0 to 2π and permitting the angle to go beyond this range by adding or subtracting 2π when the angle crosses from the fourth to the first quadrant or from first to the fourth quadrant.

This calculation is described as follows:

$$\psi_{BE} = \begin{cases} \psi_B + 2n\pi & \psi_B \geq 0 \\ (2\pi + \psi_B) + 2n\pi & \psi_B < 0 \end{cases} \quad (76)$$

where ψ_{BE} is the extended Euler angle and n is determined by maintaining a record of the first/fourth quadrant crossings as ψ_B varies with time. To illustrate this, let the index of discrete time points at which trajectory data are given be i which takes values of $i = 1, 2, \dots, k$ for k breakpoints, then

$$n = 0 \text{ for } i = 1 \quad (77)$$

$$\Delta\psi_{B_i} = \psi_{BE_i} - \psi_{BE_{i-1}} \quad i = 2, 3, \dots, k \quad (78)$$

$$n = n + 1 \text{ when } \Delta\psi_{B_i} < -\pi \quad (79)$$

$$n = n - 1 \text{ when } \Delta\psi_{B_i} > \pi \quad (80)$$

This process is applied to the calculation of ψ_B since this Euler angle is most likely to require extension beyond principal values. It should be recognized that the Euler angle calculation contains limitations on the range of θ_B to $\pm\pi/2$ and ϕ_B to $\pm\pi$, and that ϕ_B is calculated by assuming that the vehicle makes coordinated turns.

VI. COMPUTER PROGRAM

A computer program has been written to generate the sets of spline interpolation coefficients which represent a vehicle trajectory and the corresponding Euler angles. The program is intended for use in an offline mode where the trajectory coefficients are punched on cards or written to some other peripheral device for use in a missile-target intercept simulation which requires a moving target.

All three options described in Section IV are included in the program. The user selects a desired option via the program's input data. The program is written in FORTRAN for a CDC 6600 series machine. A listing is contained in Appendix A.

A. Program Composition

The program consists of the main program which performs the input/output operations, calculates accelerations and angle of attack, performs coordinate frame transformation, and controls the overall operation and the following subroutines:

- 1) AVELIN - Calculates cubic spline interpolation coefficients for three functions of one independent variable.
- 2) RK4 - Performs Runge-Kutta fourth order integration of velocity frame rotational rates, longitudinal acceleration, and inertial frame velocities.
- 3) ATTAK - Interpolates in a trajectory using coefficients produced by AVELIN. First and second derivatives are also calculated plus angles ψ_{T0} and θ_{T0} for the case of trajectory X, Y, Z coordinates.
- 4) ATMOS - Calculates atmospheric density as a function of altitude.
- 5) GRVALT - Calculates local gravitational acceleration and vehicle altitude above the earth's surface as a function of position.

B. Input Data

Each trajectory generated requires one set of input data cards which contains the following elements, punched according to the given formats.

1. Title Cards. These are punched free field and are intended to contain a descriptive heading for the trajectory. The number of title cards is unrestricted; the last card must contain ENDT in columns 1 to 4 and blanks in columns 5 to 10.

2. Trajectory, Option and Breakpoint Numbers. This card contains three integers punched in 315 format. The first integer is a trajectory identification number and must be an integer in the range 1 to 5; the second number selects the input data option (Paragraph VI.A.5) and must be an integer in the range 1 to 3. The third integer is the number of points in time (breakpoints) at which input data are provided; the range of this number is 3 to 100.

3. Euler Angle Indicator and Angle of Attack Data.

This card contains up to eight entries punched in floating point format 8F10.0. The first entry is an indicator to determine whether vehicle Euler angle interpolation coefficients are required to be output — a zero value indicates that Euler angles are not required, in which case the next six parameters on this card are unused and may be set equal to zero; i.e., only g_0 is required. The remaining seven parameters have the following meaning:

$$\frac{dC_L}{d\alpha}_1 = \text{Lift curve slope (rad)}$$

α_1 = Expressed in degrees

$$\frac{dC_L}{d\alpha}_2 = \text{Lift curve slope (rad)}$$

$\frac{W}{S}$ = Wing loading in appropriate units (Paragraph VI.D.)

ρ_{SL} = Sea-level air density in appropriate units

H_{NORM} = Number of feet per unit of length in which the trajectory is expressed

g_0 = Sea-level gravitational acceleration in units consistent with the trajectory data.

4. Output Reference Frame Transformation Data.

This card contains six quantities read in 6F10.0 format and represent the translation and rotation of the output reference frame. The data are \underline{r}_0 as components X_0, Y_0, Z_0 in the same units as the trajectory and ψ_0, θ_0, ϕ_0 in degrees.

5. Trajectory Input Data.

All data are read with a format of 8F10.0. Card contents depend on the option number in Paragraph VI.A.2 as follows:

(a) Option 1 — Each card contains two sets of data (except the last card which may contain only one set) containing values of time and associated values of X, Y, Z trajectory coordinates relative to the input reference frame. Time is required to be expressed in units of seconds and trajectory coordinates in units which are selectable by the user (Paragraph VI.D).

(b) Option 2 — The first card must contain the three position coordinates and three velocity components of the vehicle relative to the input frame, at the first time breakpoint contained in the subsequent data.

Subsequent cards contain two sets of data, as in option 1, but each set consists of time in seconds and acceleration in units of g along the vehicle velocity reference axes.

(c) Option 3 — Data for this option is similar to option 2. The first card contains an identical set of parameters, and subsequent cards contain sets of four items consisting of time, acceleration along the velocity frame X axis and angles ψ_T and θ_T of the velocity frame relative to the input frame. Angles are required to be expressed in degrees.

Note that in all three options, the number of sets of data consisting of time and three associated parameters is given by the third integer of the first data card after the title. Example sets of input data cards are given in Appendix B.

C. Output of Results

Results are output by the program in two forms. Trajectory results, in which the piecewise interpolation coefficients and associated times are included, are output to logical unit 7 (TAPE7 in CDC 6600 SCOPE) preceded by the title read from the input data. This part of the output contains the following records, all in 80 column card image format:

- 1) Title records identical to the input title terminated by a record containing ENDT in positions 1 to 4 and blanks in positions 5 to 10.
- 2) A record containing the trajectory number in the fifth character position and the number of sets of interpolation coefficients in the ninth and tenth character positions. This latter number is always one less than the number of time breakpoints contained in the input data.
- 3) Interpolation coefficients and their associated time breakpoint in the order $a_0, a_1, a_2, a_3, b_0, b_1, b_2, b_3, c_0, c_1, c_2, c_3, t$ where $a_i, b_i, c_i, i = 1, 2, 3$ are respectively X, Y, Z coordinate coefficients. Each record containing these data has the trajectory number and the record sequence number contained in the first five positions of the record in the format I2, I3. The remainder of the record contains interpolation data in the format 7E15.7 output as a string starting with the first time breakpoint set.

4) For the case where Euler angle interpolation coefficients are required, these results are output in identical format to 3) in the foregoing. Sequence numbers are reset to commence with 1 for this set.

The second form of the output consists of printed results which includes the input data suitably annotated, the interpolation coefficients, and the vehicle trajectory at 0.25-sec intervals over the input time span. The printed trajectory is obtained by use of the piecewise interpolation coefficients. In addition, if the Euler angle option has been selected, the Euler angle and angle of attack input data (generated within the program), interpolation coefficients and interpolated Euler angles at 0.25-sec intervals are printed. Additionally, the resultant lateral accelerations (along velocity frame Y and Z axes) in terms of g are printed with the interpolated trajectory position and velocity data.

Sets of example printed results are given in Appendix B.

D. Dimensions and Units

The program is designed to permit the user to select the physical dimensions and units of the final output trajectory data. For this purpose the input data must be consistent within the desired units system. Units must be chosen for the following input data:

- 1) Option 1 position data.
- 2) Options 2 and 3 gravitational acceleration and initial position and velocity.
- 3) For the angle of attack option: Vehicle wing loading, sea level air density, altitude normalizing parameter H_{NORM} .
- 4) Output frame origin shift relative to input frame.

Table 1 contains the units of each of the above for the British and SI systems.

E. Error Messages

The following error message may occur followed by program termination:

TRAJECTORY NUMBER OUT OF RANGE XXX OR TOO MANY SEGMENTS XXX

where XXX are respectively the trajectory number and number of breakpoints read from the input data. This message appears when the trajectory number is greater than 5 or less than 1, or when the number of breakpoints exceeds 100.

TABLE 1. INPUT DATA UNITS FOR BRITISH AND SI SYSTEMS

Parameter	British	SI
Vehicle position	ft	m
Gravitational acceleration	32.17 ft/sec ²	9.807 m/sec ²
Velocity	ft/sec	m/sec
Vehicle wing loading	lb/ft ²	kg (weight)/m ²
Sea-level air density	0.002378 slugs/ft ³	0.1244 kg (mass)/m ³
Altitude normalizer H _{NORM}	1.0 ft/ft	3.280843 ft/m

LIST OF SYMBOLS

\underline{A}_0	Acceleration vector relative to the output reference frame
A_{x0}, A_{y0}, A_{z0}	Components of \underline{A}_0 along the output reference frame axes directions
A_{xv}, A_{yv}, A_{zv}	Components of vehicle acceleration along the vehicle velocity frame axes directions (velocity frame from the input frame)
$A_{xv0}, A_{yv0}, A_{zv0}$	Components of vehicle acceleration along the vehicle velocity frame axes directions (velocity frame from the output frame)
a_0, a_1, a_2, a_3	Coefficients of the piecewise cubic polynomials
$[B_{ij}]$	Tridiagonal matrix of independent variable breakpoint intervals for calculation of cubic spline coefficients [Equation (37)]
\underline{c}	Vector function of independent variable intervals and dependent function values required for calculation of cubic spline coefficients [Equations (37) and (39)]
C_L	Vehicle lift coefficient
D	Operator representing d/dx
F	Interpolated function representing f the true function
f_i	Function values, to which the piecewise splines are fitted, at the i th independent variable breakpoint
f'_i	Df_i
g	Local gravitational acceleration (magnitude)
g_0	Sea-level gravitational acceleration (magnitude)
\underline{g}_0	Gravitational acceleration vector in the output reference frame
g_{x0}, g_{y0}, g_{z0}	Components of gravitational acceleration along the output frame axes directions

g_{yv0}, g_{zv0}	Components of gravitational acceleration along the velocity frame axes directions (velocity frame from the output frame)
H	Vehicle altitude above the earth's surface
H_{NORM}	Units parameter: number of feet per linear unit of the trajectory data
$h_1(x), h'_1(x)$	Cubic polynomial piecewise interpolation basis functions
i, j, k	Integer indices
L	Vehicle aerodynamic lift
N	The number of independent variable breakpoints over the interpolated range is $N + 2$
n	Integer index
$p(x)$	Piecewise cubic polynomial
$q(x)$	Piecewise cubic polynomial
R_0	Radius of the earth
\underline{r}_{in}	Position vector relative to the input reference frame
$r_k(x)$	Piecewise cubic polynomial
\underline{z}_0	Translation of the output frame origin relative to the input frame
\underline{r}_{out}	Position vector relative to the output reference frame
S	Vehicle wing area
$[T]_{OI}$	Direction cosine matrix of the output reference frame relative to the input reference frame
$[T]_{v0}$	Matrix of direction cosines between the output reference frame and the vehicle velocity frame
t	Time
$[t_\alpha], [t_\phi], [t_\theta], [t_\psi]$	Component transformation matrices which form $[T]_{v0}$

t_1	Discrete breakpoints in time at which trajectory data are given
V	Magnitude of vehicle velocity
V_{XI}, V_{YI}, V_{ZI}	Velocity components along the input reference frame axes directions
$V_{XIC}, V_{YIC}, V_{ZIC}$	Initial condition velocity components in the input reference frame
V_{x0}, V_{y0}, V_{z0}	Velocity components along the output reference frame axes directions
W	Vehicle weight
X_{in}, Y_{in}, Z_{in}	Input reference frame axes
X_I, Y_I, Z_I	Coordinates relative to the input reference frame
X_0, Y_0, Z_0	Components of \underline{r}_0 relative to the input frame
$X_{out}, Y_{out}, Z_{out}$	Output reference frame axes
X_v, Y_v, Z_v	Velocity frame axes
X', Y', Z'	Intermediate axes between the input and output reference frames
x	Independent variable of the exact and interpolated functions f and F
x_1	Discrete values of x representing breakpoints for the interpolation process
α	Aerodynamic angle of attack (magnitude)
α_1	Angle of attack at which idealized lift curve slope changes
α_{T0}	Aerodynamic angle of attack with appropriate sign
Δf_1	Difference between successive pairs of f_1
Δx_1	Independent variable breakpoint intervals
Δx	Piecewise independent variable, $x - x_1$

$\Delta\psi_{B_i}$	Increment in vehicle Euler angle ψ_B between the i th and $(i - 1)$ th breakpoints
Δt	Piecewise time variable for trajectory interpolation
δ_{ij}	Kronecker delta function (0 when $i \neq j$, 1 when $i = j$)
$n_{k,i}(x)$	Lagrange interpolating polynomial basis functions
ψ_B, θ_B, ϕ_B	Vehicle Euler angles relative to the output reference frame
ψ_O, θ_O, ϕ_O	Euler angles of the output reference frame relative to the input reference frame
ψ_T, θ_T	Euler angles the velocity frame relative to the input reference frame
$\psi_{TO}, \theta_{TO}, \phi_{TO}$	Euler angles of the velocity frame relative to the output reference frame (but with ϕ_{TO} defined by the vehicle bank angle)
ψ_{TIC}, θ_{TIC}	Initial values of ψ_T and θ_T
ψ_{BE}	Definition of ψ_B extended beyond principal values to allow first/fourth quadrant crossings to be continuous
ρ	Ambient atmospheric density
ρ_{SL}	Sea-level atmospheric density

Appendix A. COMPUTER PROGRAM LISTING

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PROGRAM TRAJEC(INPUT,OUTPUT,PUNCH,TAPES=INPUT,TAPE6=OUTPUT,TAPE7)
C-----
C THIS PROGRAM GENERATES TRAJECTORIES IN THE FORM OF PIECEWISE
C SPLINE INTERPOLATION COEFFICIENTS AT GIVEN BREAKPOINTS IN TIME.
C
C TRAJECTORIES ARE OUTPUT IN THE FORM OF SETS OF CUBIC SPLINE
C INTERPOLATION COEFFICIENTS REPRESENTING X, Y, Z COMPONENTS OF
C A TRAJECTORY TOGETHER WITH THE ASSOCIATED TIME. THUS, THERE ARE
C 13 ITEMS FOR EACH TRAJECTORY POINT.
C
C TARGET INPUT TRAJECTORIES MAY BE SPECIFIED IN TERMS OF X, Y, AND Z
C COMPONENTS OR AS ACCELERATION COMPONENTS - LONGITUDINAL, NORMAL
C AND RADIAL - AS FUNCTIONS OF TIME. FOR THE VARIOUS INPUT OPTIONS
C SEE THE PROGRAM DOCUMENTATION.
C
C PIECEWISE SPLINE REPRESENTATION OF EULER ANGLES IS AVAILABLE AS AN
C OPTION IN WHICH CASE ANGLES OF ATTACK MAY BE INCLUDED. EULER
C ANGLES ARE CALCULATED ASSUMING COORDINATED TURNS.
C
C THE OUTPUT FRAME MAY BE TRANSFORMED BY TRANSLATION AND ROTATION,
C RELATIVE TO THE INPUT DATA REFERENCE FRAME.
C
C OUTPUT OF THE INTERPOLATION COEFFICIENTS IS TO UNIT 7 IN CARD
C IMAGE FORMAT (I2,I3,5E15.8) WHERE THE 2 INTEGERS ON EACH CARD
C ARE TRAJECTORY NUMBER (1 TO 5) AND A SEQUENCE NUMBER. COEFFICIENTS
C ARE IN THE ORDER A0, A1, A2,....T AT EACH POINT.
C
C A.C. JOLLY, DECEMBER 1975.
C-----
C DIMENSION      TRAJ(13,99),      XTRAJ(1287),      XYZ(3,100)
C DIMENSION      LABEL(8), TIME(100), TM(3,3), XYZC(3)
C EQUIVALENCE     (TRAJ,XTRAJ)
C DIMENSION      X(100), XLAM(100),XMU(100), P(100), Q(100)
C 1              , XM(100), A2(3,100),A3(3,100)
C DIMENSION      VOL(100), VON(100), VDR(100)
C COMMON /RKTGT/ VT, PSIT, THET, RT(3), VT(3)
C COMMON /TGT/ ITME, RT(3), VT(3), ANGL(3), ACC(3)
C DATA          RTD/57.2957795/, PI/3.141592654/
C DATA          TWOPI/6.283185318/
C
C *** INTERPOLATION STATEMENT FUNCTION
C
C FINT(ACC,TINT,IJ) = ACC(IJ)*TINT*(ACC(IJ+1)-ACC(IJ))
C
C *** READ AND OUTPUT TRAJECTORY TITLE.
C
C NPAGE = 1
C WRITE (6,97) NPAGE
C NPAGE = NPAGE+1
C LINES = 3
C NPASS = 1
C 1 READ (5,93) LABEL
C IF (2OF(5).NE.0)GO TO 1000
C WRITE (6,93) LABEL
C LINES = LINES+1
C WRITE (7,93) LABEL
C IF (LABEL(1).NE.1)CHENDT 1GO TO 10

```

```

      DO 5 I=1,99
      TRAJ(13,I) = -1.26
C
C *** READ TRAJECTORY NUMBER AND TRAJECTORY GENERATOR OPTION AND
C *** NUMBER OF TRAJECTORY POINTS (UP TO A MAXIMUM OF 21)
C
      READ (5,910) ITRAJ,IOPT,NSEG
      WRITE (6,890) ITRAJ, IOPT, NSEG
      LINES = LINES+3
      IF (ITRAJ.LE.5 .AND. ITRAJ.GT.0 .AND.NSEG.LE.100)GO TO 2)
      WRITE (6,920) ITRAJ, IOPT, NSEG
      STOP
C
C *** READ ANGLE OF ATTACK DATA
C
      2. READ (5,940) AIND,SLOPE1,ALFA1,SLOPE2,WOS,RHOSL,HNORM,G0
      IF (AIND.NE.0.)WRITE (6,950) SLOPE1,ALFA1,SLOPE2,WOS,RHOSL,HNORM
      IF (AIND.NE.0.)LINES = LINES+4
      ALFA1 = ALFA1/RTD
C
C *** READ FRAME TRANSFORMATION DATA FOR TRANSFORMING TO THE OUTPUT
C *** TRAJECTORY FRAME. TRANSFORMATION PARAMETERS ARE TRANSLATION AND
C *** ROTATION COMPONENTS, THE LATTER IN DEGREES, THE FORMER IN
C *** CONSISTENTLY APPROPRIATE UNITS.
C
      READ (5,940) XYZ0, PSIO, THET0, PHI0
      WRITE (6,840) XYZ0, PSIO, THET0, PHI0
      WRITE (6,995)
      LINES = LINES+7
      GO TO (30,50,50)IOPT
C
C *** TRAJECTORY INPUT AS A SERIES OF X, Y, Z COORDINATES
C
      3. NCARDS = NSEG/2
      IF (NCARDS*2.NE.NSEG)NCARDS = NCARDS+1
      DO 4 I=1,NCARDS
      J = 2*(I-1)+1
      READ (5,940) TIME(J), XYZ(1,J), XYZ(2,J), XYZ(3,J),
      1 TIME(J+1),XYZ(1,J+1), XYZ(2,J+1), XYZ(3,J+1)
      WRITE (6,880) TIME(J), XYZ(1,J), XYZ(2,J), XYZ(3,J),
      1 TIME(J+1), XYZ(1,J+1), XYZ(2,J+1), XYZ(3,J+1)
      LINES = LINES+2
      4. CONTINUE
      GO TO 170
C
C *** OPTION 2. LONGITUDINAL, NORMAL AND HORIZONTAL ACCELERATIONS (IN
C *** G-S) ARE INPUT FOR EACH OF NSEG FLIGHT SEGMENTS. THE ACCELERATIONS
C *** ARE DEFINED IN A TARGET FRAME WHOSE X1-AXIS IS THE TARGET VELOCITY
C *** AND WHICH DOES NOT ROLL WITH THE TARGET. ACCELERATIONS ARE
C *** INTEGRATED IN AN INERTIAL FRAME TO YIELD THE TRAJECTORY OF
C *** POSITION DATA TO WHICH THE CUBIC SPLINE IS FITTED.
C
C *** FIRST READ TARGET INITIAL POSITION AND VELOCITY IN THE INERTIAL
C *** FRAME
C
      5. READ (5,940) RT0, VY0
C

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PROGRAM TRAJEC

76/74 OPT=1

FTM 4.2+74355

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C *** NEXT THE SETS OF ACCELERATION COMPONENTS AND ASSOCIATED TIMES
C
  NCARDS = NSEG/2
  IF (NCARDS*2.NE.NSEG)NCARDS = NCARDS+1
  DO FC I=1,NCARDS
    J = 2*(I-1)+1
    READ (3,340) TIME(J), VOL(J), VDR(J), VON(J),
1      TIME(J+1), VOL(J+1), VDR(J+1), VON(J+1)
    WRITE (6,387) TIME(J), VOL(J), VDR(J), VON(J),
1      TIME(J+1), VOL(J+1), VDR(J+1), VON(J+1)
    LINES = LINES+2
  CONTINUE
  IF (IOPT.EQ.3)GO TO 100

C
C *** CALCULATE TARGET INITIAL CONDITIONS
C
  TEMPI = VT0(1)*VT0(1)+VT0(2)*VT0(2)
  VET = SQRT(TEMPI+VT0(3)*VT0(3))
  PSI7 = ATAN2(VT0(2),VT0(1))
  THET = ATAN2(-VT0(3),SQRT(TEMPI))
  CONTINUE
  XYZ(1,1) = PT0(1)
  XYZ(2,1) = RT0(2)
  XYZ(3,1) = RT0(3)

C
C *** DIVIDE EACH TIME SEGMENT INTO 10 STEPS FOR INTEGRATION AND
C *** CALCULATE TARGET POSITION BY RK-4 NUMERICAL INTEGRATION.
C
  JUP = NSEG-1
  DO AL I=1,JUP
    DELT = TIME(I+1)-TIME(I)
    DT = DELT/10.
    T = TIME(I)
    CALL G-VALT(G0,RT0,HNORM,G,ALT)
    VOLONG = G*VOL(I)
    VONCRM = G*VON(I)
    VORACL = G*VDR(I)
    DO 70 J=1,10
      IF (IOPT.EQ.3)GO TO 70
      TINT = (T-TIME(I))/DELT
      VOLONG = G*FINT(VOL,TINT,I)
      VORACL = G*FINT(VDR,TINT,I)
      VONCRM = G*FINT(VON,TINT,I)
7    CALL RK4(VOLONG,VORACL,VONCRM,T,DT)
      XYZ(1,I+1) = RT0(1)
      XYZ(2,I+1) = RT0(2)
8    XYZ(3,I+1) = RT0(3)
      GO TO 171

C
C *** OPTION 3. TRAJECTORY DATA ARE SPECIFIED AS LONGITUDINAL ACCEL-
C *** ERATION, TARGET FRAME PSIT AND TARGET FRAME THET AS ARBITRARY
C *** FUNCTIONS OF TIME. PSIT AND THET FUNCTIONS ARE CONVERTED TO
C *** EQUIVALENT ACCELERATIONS WHICH ARE INTEGRATED AS FOR OPTION 2.
C
10  PSIT = VDR(1)/RT0
    THET = VON(1)/RT0
    VTI = VT0(1)

```

```

      MSG = NSEG-1
      CALL C-VALT(IG0,RTC,MNORM,G,ALT)
      DO 11 I=1,MSEG
      DT = TIME(I+1)-TIME(I)
      VTI = VTI+DT*.5*(VDL(I)+VDL(I+1))*G
      TM(TM) = .5*(VON(I)+VON(I+1))/RTD
      QA = VTI/(DT*RTD*G)
      ZF = QA*(VON(I+1)-VON(I))
      QA = QA*COS(THETH)*(VDR(I+1)-VDR(I))
      VDR(I) = QA
      VDN(I) = -ZF
11.  CONTINUE
      VDR(NSEG) = 0.
      VDN(NSEG) = 0.
C
C *** CALCULATE TARGET INITIAL CONDITIONS
C
      VTI = VT(1)
      VT(1) = VTI*COS(THET)*COS(PSTI)
      VT(2) = VTI*SIN(-THET)
      VT(3) = VTI*COS(THET)*SIN(PSTI)
      GO TO 15
C
C *** TRANSFORM TARGET POSITION COORDINATES TO THE OUTPUT FRAME.
C
17.  CSI = COS(PSTI/RTD)
      SSI = SIN(PSTI/RTD)
      CTH = COS(THET/RTD)
      STH = SIN(THET/RTD)
      CFI = COS(PHI/RTD)
      SFI = SIN(PHI/RTD)
      TM(1,1) = CSI*CTH
      TM(2,1) = STH*CSI*SFI-SSI*CFI
      TM(3,1) = STH*CSI*CFI+SSI*SFI
      TM(1,2) = CTH*SSI
      TM(2,2) = CSI*CFI+STH*SSI*SFI
      TM(3,2) = STH*SSI*CFI-CSI*SFI
      TM(1,3) = -STH
      TM(2,3) = CTH*SFI
      TM(3,3) = CTH*CFI
      DO 19 I=1,NSEG
      DO 16 J=1,3
18.  RTC(J) = XYZ(J,I)-XYZD(J)
      DO 19 J=1,3
19.  XYZ(J,I) = TM(J,1)*RTC(1)+TM(J,2)*RTC(2)+TM(J,3)*RTC(3)
C
C *** NOW CALCULATE CUBIC SPLINE COEFFICIENTS
C
20.  CALL AVELIN(TIME,XYZ,NSEG,3,M,XLAM,XMU,P,Q,XM,A2,A3,TRAJ)
C
C *** PRINT INTERPOLATION COEFFICIENTS
C
      MSG = NSEG-1
      WRITE (6,833)
      LINE = LINE+2
      DO 25 I=1,MSEG
      WRITE (6,820) TRAJ(13,I),(TRAJ(J,I),J=1,12)

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PROGRAM TRAJEC 74/74 OPT=1

FTN 4.2+74335

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      LINES = LINES+4
      IF (LINES.LT.95) GO TO 250
      WRITE (6,873) NPAGE
      NPAGE = NPAGE+1
      LINES = 3
25    CONTINUE
      LINES = LINES+2
C
C *** OUTPUT THE INTERPOLATION COEFFICIENTS AND TIME TO UNIT 7 IN A
C     STOPING STARTING AT TRAJ(1,1) PLUS TRAJECTORY AND SEQUENCE
C     NUMBERS ON EACH CARD.
C
      MSEG = (NSEG-1)*13
      I = 1
      ISEQ = 1
21    J = I+~
      IF (J.GT.MSEG) J=MSEG
      WRITE (7,953) ITRAJ, ISEQ, (XYTRAJ(K),K=I,J)
      I = J+1
      ISEQ = ISEQ+1
      IF (J.LT.MSEG) GO TO 210
C
C *** GENERATE TARGET POSITION AND RATE TERMS AT 1/4 SECOND INTERVALS
C
      TTME = 0.
      DT = .25
      JUF = IFIX(TIME(NSEG)/DT)+1
      WRITE (6,963)
      IF (NFASS.EQ.0) WRITE (6,973)
      IF (NFASS.NE.0) WRITE (6,975)
      LINES = LINES+1
      DO 22: I=1,JUP
      CALL ATTAK(TRAJ)
      CALL GRAVAL(GO,RT,MNORM,G,ALT)
      CSI = COS(ANGL(1))
      SSI = SIN(ANGL(1))
      CTH = COS(ANGL(2))
      STH = SIN(ANGL(2))
      YACC = -ACC(1)*SSI+ACC(2)*CSI
      ZACC = ACC(1)*CSI*STH+ACC(2)*SSI*STH+ACC(3)*CTH
      YACC = SQRT(YACC*YACC+ZACC*ZACC)/G
      PSIT = ANGL(1)*RTD
      THET = ANGL(2)*RTD
      IF (NFASS.EQ.0) WRITE (6,980) TTME,RT,VT,PSIT,THET,YACC
      IF (NFASS.EQ.0) GO TO 206
      DO 205 J=1,3
      RT(J) = RT(J)*RTD
205  VT(J) = VT(J)*RTD
      WRITE (6,995) TTME, RT, VT
206  CONTINUE
      LINES = LINES+1
      IF (LINES.LT.60) GO TO 215
      WRITE (6,873) NPAGE
      NPAGE = NPAGE+1
      LINES = 3
215  CONTINUE
      TTME = TTME+DT

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PROGRAM TRAJEC

74/74

OPT=1

FTN 4.2+74355

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22  CONTINUE
    WRITE (6,39)
    LINES = LINES+4
    IF (LINES.LT.58)GO TO 225
    WRITE (6,87)
    LINES = 3
225 CONTINUE
C
C *** CALCULATE TARGET EULER ANGLES INCLUDING ANGLES OF ATTACK.
C *** TANGENT COEFFICIENTS ARE CALCULATED FROM LIFT CURVE SLOPES
C *** AND WING LOADING.
C
    IF (AIND.EQ.0.)GO TO 4
    WRITE (6,86)
    LINES = LINES+6
    CALL FLESET(TRAJ)
    NREV = 0
    DO 23 I=1,NSEG
    TIME = TIME(I)
    CALL ATTAK(TRAJ)
    CALL GRVALT(GO,RT ,HNORM,G,ALT)
    CALL ATMOS(ALT,RHOSL,RHO)
    QA = .6*RHO*(VT(1)*VT(1)+VT(2)*VT(2)+VT(3)*VT(3))
C
C *** TRANSFORM GRAVITY TO OUTPUT FRAME
C
    GX = G*TH(1,3)
    GY = G*TH(2,3)
    GZ = G*TH(3,3)
C
C *** TRANSFORM ACCELERATION AND OUTPUT FRAME GRAVITY TO VELOCITY FRAME
C
    CSI = COS(ANGL(1))
    SSI = SIN(ANGL(1))
    CTH = COS(ANGL(2))
    STH = SIN(ANGL(2))
    YACC = (GX0-ACC(1))*SSI+(ACC(2)-GY0)*CSI
    ZACC = (GX0-ACC(1))*CSI*STH+(GY0-ACC(2))*SSI*STH+(GZ0-ACC(3))*CTH
    IF (ABS(ZACC).LT.1.E-30)GO TO 235
    ANGL(3) = ATAN(YACC/ZACC)
    GO TO 238
235 ANGL(3) = 0.
238 CONTINUE
    ZF = WOS*SQRT(YACC*YACC+ZACC*ZACC)/G
    ALFT = ZF/QA/SLOPE1
    IF (ALFT.LE.ALFA1)GO TO 240
    ALFT = (ZF/QA-ALFA1*SLOPE1)/SLOPE2+ALFA1
240 IF (ZACC.LT.0.)ALFT = -ALFT
    CFI = COS(ANGL(3))
    SFI = SIN(ANGL(3))
    CAL = COS(ALFT)
    SAL = SIN(ALFT)
    XYZ(1,I) = ATAN2((CTH*SSI*CAL-STH*CSI*CFI*SAL),(CTH*CSI*CAL-
1 SSI*SFI*SAL))
    XYZ(2,I) = ASIN(STH*CAL+CTH*CFI*SAL)
    XYZ(3,I) = ATAN2(CTH*SFI,(CTH*CFI*CAL-STH*SAL))
    SI = XYZ(1,I)

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```

      IF (Z1.LT.0.1SF * SI+THOPI
      IF (I1.EQ.1)GO TO 248
      ZF = SY-SIPP
      IF (ZF.GT.PI)NREV = NACV-1
      IF (ZF.LT.-PI)NREV = NACV+1
243  SIFF = SI
      XYZ(1,I) = SY+NREV*THOPI
      PSIT = XYZ(1,I)*RYO
      THET = XYZ(2,I)*RYO
      FIT = XYZ(3,I)*RYO
      ALFT = ALFT*RYO
      WRITE (6,995) TYNE,PSIT,THET,FIT,ALFT
      LINES = LINES+1
      IF (LINES.LT.66)GO TO 233
      WRITE (6,973) NPAGE
      NPAGE = NPAGE+1
      LINES = 3
233  CONTINUE
      AIND = 0.
      NPASS = 1
      GO TO 203
1400  WRITE (6,963)
      STOP
82   FORMAT (15X F10.3, 3(4(5X E15.8)/25X))
83   FORMAT (1H0, 47X 33HSPLINE INTERPOLATION COEFFICIENTS)
84   FORMAT (1H0, 50X 27HOUTPUT FRAME TRANSFORMATION, / 17X 2HXO, 17X
      1 2HYO, 17X 2HZO, 16X 9HPSI( DEG), 9X 10HMET( DEG), 10X 9HPSYC( DEG
      2), / 3X 6F19.2)
85   FORMAT (1H0, 46X 34HEULER ANGLE INTERPOLATION SELECTED, / 10X
      1 9HIECL/DA1, 14X 5HALFA1, 10X 9H(DCL/DA)2, 16X 3HW/S, 14X 5HRHOSL
      2, 14X 5HMCNM, / 4(9X F10.3), 2(9X F10.5))
86   FORMAT (// 48X 37HEULER ANGLES AND ANGLE OF ATTACK( DEG), / 42X
      1 4HTIME, 8X 3HPSI, 6X 5HTHETA, 8X 3HPHI, 7X 4HALFA:
87   FORMAT (1H1, 36X 55HTRAJECTORY GENERATION BY PIECEWISE SPLINE INTE
      1PPOLATION, / 37X 55(1H-), 3X 4HPAGE, 13 /)
88   FORMAT (45X 4F10.3)
89   FORMAT (1H0, / 30X 17HTRAJECTORY NO. = , I2, 10X 13HOPTION NO. = ,
      1 I2, 10X 21HNO. OF BREAKPOINTS = , I3)
89   FORMAT (// 50X 12HINPUT TABLES, / 5X 4HTIME, 5X 6HX COMP, 4X
      1 2HY COMP, 4X 6HZ COMP)
90   FORMAT (20X 10(1H*), 8A10, 10(1H*))
91   FORMAT (3I5)
92   FORMAT (// 20X *TRAJECTORY NUMBER OUT OF RANGE*, 2X I5, *OR TOO MA
      1NY SEGMENTS* 2X I5)
94   FORMAT (3F10.3)
93   FORMAT (8A10)
95   FORMAT (I2, I3, 5E15.8)
96   FORMAT (// 20X *END OF RUN*)
96   FORMAT (// 30X 72HINTERPOLATED TRAJECTORY DATA(LINEAR UNITS FROM I
      1INPUT, ANGLES IN DEGREES) )
97   FORMAT(10X 4HTIME, 10X 1HX, 11X 1HY, 11X 1HZ, 9X 4HXDOT,
      16X 4HYDOT, 8X 4HZDOT, 8X 4HPSIT, 7X 6HTHETAT, 4X 13HLAT ACC(G))
97   FORMAT ( 27X 4HTIME,10X 4HPSIT, 8X 4HMET, 8X 4HPHIT, 7X
      1 5HPSITD, 7X 5HMETD, 7X 5HPHITD)
98   FORMAT (7X F8.3, 8F12.3)
98   FORMAT (35X 5F11.2)
99   FORMAT (////)

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99   FORMAT (21X 7F12.2)
      END

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ROUTINE AVFLIN

74/74 OPT=1

FTN 4.2+74355

04/14/7

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SUBROUTINE AVFLIN(TIME,XYZ,N,NY,H,XLAM,XMU,P,Q,XN,AZ,AJ,TRAJ)
C-----
C   THIS SUBROUTINE CALCULATES SPLINE INTERPOLATION COEFFICIENTS
C   TO FIT THE X, Y, Z COORDINATES TRANSMITTED IN ARRAY XYZ.
C   THE NUMBER OF SETS OF DEPENDENT VARIABLES IS GIVEN BY NY AND THE
C   NUMBER OF BREAKPOINTS IN THE INDEPENDENT VARIABLE IS N.
C-----
      DIMENSION      XYZ(3,22),TRAJ(13,2 ),      H(1),      XLAM(1),
1      XMU(1),      P(1),      Q(1),      XN(NY,1), AZ(NY,1),
2      AJ(NY,1), TIME(1)

C *** CALCULATE INTERVAL IN THE INDEPENDENT VARIABLE.
C
      DO 5 K=2,N
5      P(K) = TIME(K)-TIME(K-1)

C *** CALCULATE CONDITIONS AT THE EXTREMITIES.
C
      I = 2
      J = 1
      K = 1
10     X0 = TIME(I-1)
      X1 = TIME(I)
      X2 = TIME(I+1)
      X01 = X0*X0
      X11 = X1*X1
      X22 = X2*X2
      H0 = H(I)
      H1 = X2-X0
      H2 = H(I+1)
      C = 1./H0/H1/H2
      C1 = 2.*TIME(J)
      DO 20 IY=1,NY
      Y0 = XYZ(IY,I-1)
      Y1 = XYZ(IY,I)
      Y2 = XYZ(IY,I+1)
      B1 = (Y1-Y0)*X22-(Y2-Y0)*X11+(Y2-Y1)*X00
      B2 = H.*Y2-H1*Y1+H2*Y0
20     XM(IY,J) = C*(B1+B2*C1)
      GO TO(30,40)K
3     I = N-1
      J = N
      K = 2
      GO TO 10

C *** CALCULATE LAMDA, MU, P AND Q
C
40     Q(1) = -.5
      IND = N-1
      DO 50 K=2,IND
      XLAM(K) = H(K+1)/(H(K)+H(K+1))
      XMU(K) = 1.-XLAM(K)
      P(K) = 1./(XLAM(K)*Q(K-1)+2.)
50     G(K) = -XMU(K)*P(K)

C *** CALCULATE C, U AND M
C

```

ROUTINE AVELIN 74/74 OPT=1

FTN 4.2+74355

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```

      DO 70 IY=1,NY
      A2(IY,1) = XM(IY,1)
      IND = N-1
      DO 60 K=2,IND
      GA = 3.*(XLAN(K)*(XYZ(IY,K)-XYZ(IY,K-1))/H(K)+XNU(K)*
      1      (XYZ(IY,K+1)-XYZ(IY,K))/H(K+1))
      60 A2(IY,K) = (GA-XLAN(K)*A2(IY,K-1))*P(K)
      K = N-1
      DO 70 K=2,IND
      XM(IY,K) = Q(K)*XM(IY,K+1)+A2(IY,K)
      K = K-1
      70 CONTINUE
C
C *** CALCULATION OF POLYNOMIAL COEFFICIENTS
C
      DO 80 J=1,IND
      U1 = H(J+1)
      U12 = 1./U1/U1
      U13 = U12/U1
      DO 80 IY=1,NY
      Y0 = XYZ(IY,J+1)-XYZ(IY,J)
      X0 = XM(IY,J+1)+XM(IY,J)
      X1 = X0+XM(IY,J)
      A2(IY,J) = U12*(3.*Y0-U1*X1)
      80 A3(IY,J) = U13*(U1*X0-2.*Y0)
C
C *** STORAGE OF COEFFICIENTS IN ARRAY TRAJ
C
      IND = 4*NY+1
      DO 100 K=2,N
      J = -3
      DO 90 I=1,NY
      J = J+4
      TRAJ(J,K-1) = XYZ(I,K-1)
      TRAJ(J+1,K-1) = XM(I,K-1)
      TRAJ(J+2,K-1) = A2(I,K-1)
      90 TRAJ(J+3,K-1) = A3(I,K-1)
      100 TRAJ(IND,K-1) = TIME(K-1)
      RETURN
      END

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ROUTINE RK4

74/74 OPT=1

FTN 4.2+74355

04/14/77

```

SUBROUTINE RK4(VOL,VER,VON,TIME,DT)
C-----
C   THIS SUBROUTINE INTEGRATES THE TARGET ACCELERATION AND VELOCITY
C   TO GIVE DISPLACEMENT IN AN INERTIAL FRAME. ACCELERATION COMPONENTS
C   IN THE TARGET FRAME ARE CONVERTED TO THE TARGET VELOCITY AND
C   TARGET FRAME EULER ANGLES PSIT AND THET.
C-----
COMMON /RKTGT/ TST(6), VT(3)
DIMENSION A(6), S(6), T(6), TACC(6)
DO 10 K=1,4
  TACC(1) = VOL
  CTHET = COS(TST(3))
  IF (CTHET.EQ.0.)GO TO 5
  TACC(2) = VOR/CTHET/TST(1)
  TACC(3) = -VON/TST(1)
  STHET = SIN(TST(3))
  CPSI = COS(TST(2))
  SPSI = SIN(TST(2))
  VT(1) = CTHET*CPSI*TST(1)
  VT(2) = CTHET*SPSI*TST(1)
  VT(3) = -STHET*TST(1)
  TACC(4) = VT(1)
  TACC(5) = VT(2)
  TACC(6) = VT(3)
GO TO(10,20,50,30)K
10 DO 15 I=1,6
  T(I) = TST(I)
  S(I) = TACC(I)*DT
15 TST(I) = TST(I)+.5*S(I)
GO TO 40
20 DO 25 J=1,6
  A(J) = DT*TACC(J)
  S(J) = S(J)+2.*A(J)
25 TST(J) = T(J)+.5*A(J)
GO TO 40
50 DO 55 I=1,6
  A(I) = DT*TACC(I)
  S(I) = S(I)+2.*A(I)
55 TST(I) = T(I)+A(I)
GO TO 40
30 DO 35 I=1,6
  TST(I) = T(I)+(S(I)+DT*TACC(I))/6.
35 CONTINUE
TIME = TIME+DT
RETURN
END

```

ROUTINE ATTACK

74/74 OPT=1

FTN 4.2+74355

04/14/77

```

      SUBROUTINE ATTACK(TRAJ)
C -----
C      THIS SUBROUTINE DETERMINES TARGET POSITION, VELOCITY AND
C      ACCELERATION AS A FUNCTION OF TIME BY CUBIC SPLINE INTERPOLATION
C      PRE-CALCULATED INTERPOLATION COEFFICIENTS
C      ARE STORED IN ARRAY TRAJ.
C -----
      DIMENSION      C(12),   TRAJ(13,20)
      COMMON /TGT/    TOISPL,  Y(9),   ACC(3)
      DATA           KSEG/1/

      T1 = TOISPL
      IF (TRAJ(13,KSEG).EQ.-1.E6)KSEG = 1
10    IF (T1.LT.TRAJ(13,KSEG))GO TO 20
      IF (T1.LE.TRAJ(13,KSEG+1))GO TO 30
      IF (TRAJ(13,KSEG+1).EQ.-1.E6)GO TO 30.
      KSEG = KSEG+1
      IF (KSEG.LT.20)GO TO 10
      KSEG = 20
      GO TO 30
20    KSEG = KSEG-1
      IF (KSEG.GE.1)GO TO 10
      KSEG = 1
30    DO 40 I=1,12
40    C(I) = TRAJ(I,KSEG)
      T1 = TOISPL-TRAJ(13,KSEG)
      T2 = T1*(C(3)+T1*C(4))
      T3 = T1*(C(7)+T1*C(8))
      T4 = T1*(C(11)+T1*C(12))
      Y(1) = C(1)+T1*(C(2)+T2)
      Y(2) = C(5)+T1*(C(6)+T3)
      Y(3) = C(9)+T1*(C(10)+T4)
      Y(4) = C(2)+T2+T2+T1*C(4)
      Y(5) = C(6)+T3+T3+T1*C(8)
      Y(6) = C(10)+T4+T4+T1*C(12)
      Y(7) = ATAN2(Y(5),Y(4))
      Y(8) = ATAN2(-Y(6),SQRT(Y(4)*Y(4)+Y(5)*Y(5)))
      Y(9) = 0.
      ACC(1) = 2.*C(3)+6.*C(4)*T1
      ACC(2) = 2.*C(7)+6.*C(8)*T1
      ACC(3) = 2.*C(11)+6.*C(12)*T1
      RETURN
      ENTFY RESET
      KSEG = 1
      END

```

ROUTINE ATMOS

74/74 OPT=1

FTN 4.2+74355

04/14/77

SUBROUTINE ATMOS(H,RHOSL,RHO)

```

C-----
C THIS SUBROUTINE CALCULATES ATMOSPHERIC DENSITY AS A FUNCTION
C OF ALTITUDE. DENSITY TABLE IS NORMALIZED BY ITS SEA LEVEL VALUE
C SO THAT DIMENSIONS OF RHO ARE THOSE OF INPUT PARAMETER RHOSL.
C THE ALTITUDE TABLE IS NORMALIZED INTO UNITS OF 1000 FEET. IF TARGET
C ALTITUDE IS EXPRESSED IN METERS THE PARAMETER HNORM IN THE MAIN
C PROGRAM MUST BE 3.280843.
C-----

```

```

DIMENSION ALTTB(32),RHOTB(32)

```

```

DATA ALTTB/ 3., 1., 2., 3., 4.,
5., 6., 7., 8., 9.,
10., 12., 14., 16., 18.,
20., 22., 24., 26., 28.,
30., 32., 34., 36., 40.,
46., 50., 60., 70., 90.,
90., 100./

```

```

DATA RHOTB/ 1., .97138, .94276, .91498, .88805,
.86195, .83586, .81061, .78620, .76221,
.73864, .69318, .65025, .60943, .57029,
.53325, .49790, .46465, .43308, .40320,
.37483, .34806, .32273, .29891, .24714,
.18544, .15311, .094865, .058881, .036532,
.023089, .0132/

```

```

HI = ABS(H)/1000.

```

```

DO 10 I=2,32

```

```

IF (HI.GE.ALTTB(I-1).AND. HI.LE.ALTTB(I))GO TO 20

```

```

10 CONTINUE

```

```

I = 32

```

```

20 RHO = (RHOTB(I-1)+(RHOTB(I)-RHOTB(I-1))*(HI-ALTTB(I-1))
/ (ALTTB(I)-ALTTB(I-1))) * RHOSL

```

```

END

```

ROUTINE GRVALT

74/74 OPT=1

FTN 4.2+74355

04/14/77

SUBROUTINE GRVALT(GO,R,HN,G,ALT)

```

C-----
C THIS ROUTINE CALCULATES TARGET ALTITUDE ABOVE THE EARTH'S SURFACE
C AND THE LOCAL GRAVITATIONAL ACCELERATION ASSUMING A SPHERICAL
C EARTH OF RADIUS 20.9E6 FEET.
C-----

```

```

DIMENSION R(3)

```

```

DATA R0/20.89032E6/

```

```

RSQ = (R0-R(3)*HN)**2

```

```

GPR = (R(1)*R(1)+R(2)*R(2))*HN*HN

```

```

ALT = SQRT(GPR+RSQ)-R0

```

```

G = G0*R0*R0/RSQ

```

```

END

```

Appendix B. EXAMPLE TRAJECTORY RESULTS

This appendix contains a set of trajectory results corresponding to each of the three input options. In each case the Euler angle option has been selected. The first two trajectories are expressed in SI units and the third is calculated in British units.

6.000	-46277000E+04	.23088305E+03	.83358040E+01	-.1388292E+02
		.3167337E+03	.2725833E+03	-.2163049E+03
	-.22393000E+04	-.80018850E+02	.22843700E+02	-.1375133E+01
1.000	-.43417000E+04	.24956377E+03	.53529379E+03	.1450090E+0E
		-.11819220E+02	-.1023571E+02	.8072513E+03
	-.29381000E+04	-.15681885E+02	.13950806E+02	-.3859211E+01
12.000	-.30417000E+04	.24906100E+03	.35023900E+03	.1265113E+01
		.44109882E+02	.38200163E+02	-.33127850E+02
	-.29381000E+04	.34455981E+01	-.43952444E+01	.37112227E+01
14.000	-.33433030E+04	.24658673E+03	-.28033388E+00	-.2382915E+01
		-.16462032E+01	-.14256350E+01	.11243775E+01
	-.29191000E+04	.3339293E+02	.1787203E+02	.1214150E+01
16.000	-.28663000E+04	.21888321E+03	-.14572424E+02	.17404894E+01
		.6143731E+01	.5321611E+01	-.41862361E+11
	-.27771000E+04	.11645723E+03	.75156077E+02	-.3687766E+01
18.000	-.24728000E+04	.19147843E+03	-.41299802E+01	.88207754E+00
		-.2292851E+00	-.19356793E+00	.15660559E+00
	-.24728000E+04	.17307178E+03	.31553985E+01	-.65564501E+00
20.000	-.21194000E+04	.17555300E+03	.11672077E+01	-.27191930E+00
		.8557808E+00	.74106860E+00	-.58445318E+00
	-.21194000E+04	.17788564E+03	-.73347352E+01	.14732581E+00
22.000	-.17658000E+04	.17695924E+03	-.4442824E+00	.17988689E+00
		-.31935489E+01	-.27656945E+01	.21812345E+01
	-.17658000E+04	.17635567E+03	.58407560E+01	.6933899E+01
24.000	-.14112000E+04	.17725997E+03	.61458388E+00	-.24728319E+00
		.11918487E+02	.18321712E+02	.99702214E+00
	-.14112000E+04	.17742169E+03	.47452129E+00	-.21768233E+00
26.000	-.10573000E+04	.17675696E+03	-.86911327E+00	-.75316798E+00
		.73109000E+02	.65169602E+02	.36817599E+00
	-.10573000E+04	.17670758E+03	-.8315727E+00	-.76113982E+00
28.000	-.71330000E+03	.16423643E+03	-.53881228E+01	-.64742451E+00
		.27163030E+03	.14512907E+02	-.85723003E+00
	-.71330000E+03	.13480311E+03	-.53982304E+01	-.86378732E+00
30.000	-.41150000E+03	.13540339E+03	-.9228333E+01	-.2134437E+00
		.50841030E+03	.1336927E+02	.28574336E+00
	-.41150000E+03	.13500851E+03	-.9225556E+01	.21282643E+00

INTERPOLATED TRAJECTORY DATA (LINEAR UNITS FROM INPUT, ANGLES IN DEGREES)

TIME	X	Y	Z	XDOT	YDOT	ZDOT	PSI	DEG	THETA	LAT
0.000	-6322.400	0.000	-1533.300	179.225	0.000	-175.325	0.000	0.000	44.530	1.597
0.250	-6370.625	0.000	-1576.421	173.750	0.000	-171.265	0.000	0.000	44.586	0.599
0.500	-6398.967	0.000	-1619.527	174.043	0.000	-169.927	0.000	0.000	44.622	0.338
0.750	-6393.755	0.000	-1660.226	176.195	0.000	-168.016	0.000	0.000	44.532	0.225
1.000	-6351.317	0.000	-1702.127	174.096	0.000	-166.614	0.000	0.000	44.615	0.267
1.250	-6367.963	0.000	-1744.636	173.795	0.000	-171.520	0.000	0.000	44.577	0.167

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

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1.500	-6.163.003	0.00	-17.00.903	170.203	.00	-17.5.203	.00	44.510	.00
1.750	-6.115.446	.00	-10.35.115	104.529	.00	-10.0.936	.00	44.443	.00
2.000	-5.965.900	0.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
2.250	-5.815.551	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
2.500	-5.667.077	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
2.750	-5.521.065	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
3.000	-5.377.712	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
3.250	-5.234.777	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
3.500	-5.092.676	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
3.750	-4.959.908	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
4.000	-4.829.311	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
4.250	-4.699.212	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
4.500	-4.569.609	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
4.750	-4.441.510	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
5.000	-4.313.623	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
5.250	-4.186.080	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
5.500	-4.059.591	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
5.750	-3.933.051	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
6.000	-3.806.566	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
6.250	-3.680.031	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
6.500	-3.553.546	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
6.750	-3.427.011	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
7.000	-3.300.476	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
7.250	-3.173.941	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
7.500	-3.047.406	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
7.750	-2.920.871	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
8.000	-2.794.336	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
8.250	-2.667.801	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
8.500	-2.541.266	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
8.750	-2.414.731	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
9.000	-2.288.196	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
9.250	-2.161.661	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
9.500	-2.035.126	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
9.750	-1.908.591	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
10.000	-1.782.056	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
10.250	-1.655.521	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
10.500	-1.528.986	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
10.750	-1.402.451	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
11.000	-1.275.916	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
11.250	-1.149.381	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
11.500	-1.022.846	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
11.750	-906.311	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
12.000	-779.776	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
12.250	-653.241	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
12.500	-526.706	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
12.750	-400.171	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
13.000	-273.636	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
13.250	-147.101	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
13.500	-20.566	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
13.750	7.969	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
14.000	15.434	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
14.250	22.899	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
14.500	30.364	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
14.750	37.829	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
15.000	45.294	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
15.250	52.759	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
15.500	60.224	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
15.750	67.689	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00
16.000	75.154	.00	-10.00.900	102.500	.00	-10.0.900	.00	44.400	.00

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

PAGE

15.75	-2921.094	-0.012	-2394.661	228.649	.822	132.513	.415	-24.138	3.562
16.12	-2466.300	1.110	-2777.100	223.647	.039	114.029	.010	-27.315	5.924
16.25	-2912.463	.018	-2746.471	212.250	.072	127.668	.029	-31.125	3.313
16.50	-2760.284	.039	-2713.041	206.051	.073	137.946	.021	-33.861	4.691
16.75	-2709.601	.030	-2677.154	200.204	.033	147.314	.013	-36.325	7.867
17.00	-2652.249	.073	-2639.154	194.901	.042	155.760	.012	-38.624	3.447
17.25	-2612.066	.078	-2599.384	190.066	.011	163.303	.003	-40.649	2.893
17.50	-2564.869	.070	-2558.190	185.648	.021	169.921	.003	-42.474	2.231
17.75	-2518.555	.046	-2515.914	181.545	.003	173.623	.006	-44.544	1.637
18.00	-2472.911	.000	-2472.911	177.996	.015	176.417	.017	-45.385	1.052
18.25	-2427.775	.067	-2429.445	179.745	.078	176.481	.085	-44.136	.802
18.50	-2383.083	.145	-2385.658	178.231	.071	175.567	.087	-44.568	.717
18.75	-2338.742	.218	-2341.661	176.939	.034	176.558	.060	-44.245	.582
19.00	-2294.669	.271	-2297.333	175.857	.017	177.436	.001	-45.258	.389
19.25	-2253.781	.291	-2252.518	175.016	.001	178.079	.003	-45.497	.232
19.50	-2216.995	.262	-2218.417	174.386	.015	179.549	.033	-45.682	.115
19.75	-2183.229	.170	-2183.890	173.975	.009	179.935	.012	-45.805	.122
20.00	-2149.463	.100	-2149.460	173.737	.042	179.117	.013	-45.965	.328
20.25	-2115.443	.251	-2117.995	176.035	1.037	177.467	.383	-45.232	.245
20.50	-2081.368	.540	-2030.676	176.443	1.632	177.162	.329	-45.115	.194
20.75	-2047.952	.812	-1986.427	176.734	.821	176.834	.282	-45.816	.188
21.00	-2014.666	1.112	-1942.238	177.072	.534	176.646	.193	-46.933	.231
21.25	-1980.666	1.386	-1898.693	177.282	.151	176.461	.039	-48.867	.302
21.50	-1946.362	.978	-1853.581	177.423	.048	176.297	.013	-49.317	.306
21.75	-1913.665	.635	-1809.887	177.497	.113	176.169	.072	-49.784	.476
22.00	-1881.506	.000	-1767.800	177.503	.025	176.375	.053	-49.767	.578
22.25	-1850.586	.937	-1721.706	176.735	.378	176.411	.129	-49.931	.235
22.50	-1820.414	.2016	-1677.594	176.675	.378	175.483	.125	-49.962	.115
22.75	-1793.264	.031	-1633.471	176.602	.322	176.573	.085	-49.931	.439
23.00	-1769.125	.378	-1589.317	176.574	.213	176.681	.073	-49.316	.772
23.25	-1746.975	.4053	-1545.124	176.595	.065	176.915	.103	-48.836	1.105
23.50	-1725.799	.3051	-1500.901	176.643	1.597	176.947	.513	-48.348	1.617
23.75	-1705.575	.2369	-1456.627	176.750	.434	177.136	.135	-48.949	1.769
24.00	-1686.300	.010	-1412.310	176.966	.756	177.283	.245	-48.336	2.108
24.25	-1667.918	3.640	-1367.918	177.475	17.453	177.577	5.617	-48.979	2.295
24.50	-1649.547	9.664	-1323.498	177.627	23.237	177.679	7.453	-48.765	2.395
24.75	-1631.114	15.155	-1279.059	177.718	29.212	177.725	9.383	-48.618	2.585
25.00	-1612.673	23.237	-1234.621	177.747	35.553	177.718	11.311	-48.433	2.695
25.25	-1594.240	32.973	-1190.287	177.745	42.085	177.636	13.323	-48.269	2.844
25.50	-1575.862	44.467	-1145.934	177.620	48.865	177.525	15.382	-48.192	2.992
25.75	-1557.536	57.811	-1101.525	177.480	55.886	177.388	17.485	-48.136	3.139
26.00	-1539.301	73.163	-1057.300	177.245	63.176	177.143	19.611	-48.274	3.284
26.25	-1521.176	93.417	-1013.187	176.036	71.452	176.626	22.631	-48.698	3.359
26.50	-1503.090	109.837	-969.249	175.124	81.042	175.113	25.049	-48.173	3.444
26.75	-1485.043	131.313	-925.558	174.035	91.315	174.333	27.427	-48.592	3.534
27.00	-1467.071	153.942	-882.185	172.753	98.932	172.751	29.765	-48.956	3.629
27.25	-1449.190	180.756	-839.201	171.283	107.540	171.299	32.133	-48.264	3.728
27.50	-1431.408	208.741	-796.674	169.625	116.230	169.646	34.433	-48.519	3.851
27.75	-1413.718	237.051	-754.687	167.778	125.132	167.833	36.715	-48.721	3.939
28.00	-1396.120	273.670	-713.301	165.723	134.157	165.770	38.983	-48.869	4.062
28.25	-1378.619	306.444	-672.005	163.530	143.378	163.510	41.243	-48.746	4.184
28.50	-1361.224	341.523	-630.615	161.210	152.439	161.212	43.491	-48.757	4.304
28.75	-1343.924	382.754	-589.424	158.960	161.495	158.955	45.691	-48.762	4.424
29.00	-1326.725	424.359	-548.588	156.540	169.257	156.533	47.817	-48.716	4.544
29.25	-1309.627	467.356	-507.956	154.066	177.335	154.062	49.863	-48.645	4.664
29.50	-1292.630	510.566	-467.517	151.542	185.193	151.542	51.833	-48.547	4.784
29.75	-1275.733	553.907	-427.277	148.966	192.843	148.966	53.753	-48.422	4.904
30.00	-1258.936	597.379	-387.238	146.336	200.283	146.336	55.613	-48.277	5.024

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

PAGE 5

30.000	-411.566	604.438	-411.560	137.233	250.282	136.278	55.763	-29.159	1.007
31.250	-375.323	558.892	-375.323	139.469	215.311	131.467	57.571	-20.212	1.796
32.500	-346.279	511.362	-346.280	125.936	212.233	125.938	59.186	-27.843	3.776
33.750	-315.348	464.907	-315.349	121.501	219.158	121.501	61.984	-25.376	3.749
35.000	-285.512	423.823	-285.512	117.147	226.184	117.147	64.175	-24.715	3.712
36.250	-256.749	387.358	-256.749	112.486	233.242	112.486	66.135	-21.537	3.668
37.500	-229.439	357.208	-229.439	108.528	241.391	113.686	67.653	-22.377	3.618
38.750	-202.563	326.363	-202.563	104.384	247.612	104.386	67.151	-21.229	3.561
40.000	-176.768	295.770	-176.768	100.223	254.994	103.228	68.535	-24.399	3.498

EULER ANGLES AND ANGLE OF ATTACK (DEG)

TIME	PSI	TETA	PHI	ALFA
0.00	359.54	46.02	.04	1.49
2.00	359.38	44.98	-1.00	.63
4.00	358.28	49.85	.04	3.67
6.00	364.59	36.50	.08	-5.15
8.00	363.67	13.56	-1.00	-7.81
10.00	360.18	-0.04	.01	-3.58
12.00	363.14	1.53	.22	3.72
14.00	359.51	-10.50	.06	-5.22
16.00	359.04	-36.76	-1.14	-9.69
18.00	359.31	-46.32	5.81	-.64
20.00	362.02	-44.08	6.47	1.83
22.00	361.46	-43.84	-42.52	1.49
24.00	363.79	-43.60	65.94	3.77
26.00	382.37	-40.79	80.47	5.39
28.00	403.21	-34.21	50.95	6.83
30.00	419.53	-25.65	42.97	5.43
32.00	431.42	-16.58	38.15	4.63

SPLINE INTERPOLATION COEFFICIENTS

1.000	.62576146E+01	.29376391E-02	-.57318817E-02
	.83319528E+00	-.93961431E-03	.60283132E-02
	.78598511E-06	.18016075E-05	-.31459876E-06
2.000	.62723532E+01	-.23244332E-01	.13325996E-01
	.78599212E+00	.25923880E-01	-.13414342E-01
	-.33006938E-05	.11574352E-06	.04233213E-01
4.000	.62183236E+01	.54911584E-01	-.17318182E-01
	.85617508E+00	-.54589819E-01	.48236445E-02
	.25919096E-05	.51733352E-05	-.47639538E-05
6.000	.63632333E+01	-.71375392E-01	.37666256E-02
	.63789361E+00	-.25274833E-01	.74931724E-02
	.47169878E-05	-.23439805E-04	.16140855E-04

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

8.000	.63368415E+01	-.37457953E-01	.5+022442E-02	-.35627652E-03
	.23665594E+00	-.19884212E+00	.13666201E-01	.08946925E-02
	-.13205103E-04	.73339876E-04	.7343059E-04	-.39335835E-04
10.000	.62863847E+01	-.11573729E-01	.75398879E-02	-.96395177E-03
	-.11327749E-01	-.29443686E-01	.51033817E-01	-.18486151E-01
	.11251661E-03	-.10495824E-03	-.16257965E-03	.14490837E-03
12.000	.62856851E+01	.71183220E-02	.17561573E-02	-.48551336E-02
	.26787735E-01	-.61854359E-02	-.4943892E-01	-.12963147E-05
	.61212451E-03	.98446762E-03	.78730257E-03	-.51173155E-03
14.000	.62747853E+01	-.34018652E-01	-.2227644E-01	.98735119E-02
	-.18321957E+00	-.20381656E+00	-.4941167E-01	.10492466E-01
	.11164576E-02	-.23270807E-02	-.23630367E-02	.1389517E-02
16.000	.61355575E+01	-.46358899E-02	.36966627E-01	-.80103788E-02
	-.6405408E+00	-.17955329E+00	.51543305E-01	-.62232368E-02
	-.2511237E-02	.39387929E-02	.54960235E-02	.11443372E-01
18.000	.62718780E+01	-.47106876E-01	-.11095846E-01	-.31419189E-03
	-.80326815E+00	-.80509078E-02	.24203885E-01	-.5846434E-02
	.11089741E+00	.16324333E+00	.74156245E-01	-.7427825E-01
20.000	.63183853E+01	-.18476111E-02	-.12980997E-01	.33909803E-02
	-.76335830E+00	.1857481E-01	-.10887022E-01	.17650612E-02
	.14778391E+00	-.43147874E+00	-.37151328E+00	.18674862E+00
22.000	.62911733E+01	-.12768729E-01	.71244386E-02	.60805235E-02
	-.76163627E+00	-.37925352E-02	-.2366544E-03	.11019113E-02
	-.73727058E+00	.32338764E+00	.74899427E+00	.22354317E+00
24.000	.63493339E+01	.98521213E-01	.48516532E-01	.83630619E-02
	-.76955266E+00	.92037925E-02	.57948172E-02	.43171532E-03
	.11589532E+01	.64267947E+00	-.58929895E+00	.12264347E+00
26.000	.66735431E+01	.19223663E+00	-.15510392E-02	.17499538E-02
	-.71191209E+00	.41563633E-01	.3851044E-02	.72918035E-03
	.11554337E+01	-.25803334E+00	.14294425E+00	-.29730375E-01
28.000	.73373573E+01	.16458378E+00	-.12161571E-01	.53644901E-03
	-.5947785E+00	.7035385E-01	.50100222E-02	-.9855732E-03
	.88938137E+00	-.35828671E-01	-.35438814E-01	.98667783E-02
30.000	.73221689E+01	.12237805E+00	-.89452956E-02	-.17868197E-03
	-.4421446E+00	.78567279E-01	-.90332395E-03	.32851913E-03
	.75804288E+00	-.67571386E-01	.18962856E-01	-.30222894E-02

INTERPOLATED TRAJECTORY DATA LINEAR UNITS FROM INPUT, ANGLES IN DEGREES

TIME	FSIT	THET	PSITO	THEID	PHITE
8.000	358.54	46.02	1.41	-1.80	-.86
10.000	358.89	45.57	1.37	-1.69	-.80
12.000	359.24	45.15	1.24	-1.53	-.80
14.000	359.54	44.79	1.04	-1.23	-.80
16.000	359.78	44.52	.75	-.86	-.86
18.000	359.91	44.37	.36	-.41	-.80

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

1.50	359.91	44.37	-0.52	-0.07	.12	-0.00
1.75	359.74	44.57	-0.00	-0.60	.74	-0.00
2.00	359.38	44.98	-0.00	-1.22	1.45	-0.00
2.25	358.84	45.60	-0.00	-2.26	2.59	-0.00
2.50	358.20	46.33	-0.00	-2.46	2.86	-0.00
2.75	357.54	47.10	-0.00	-2.47	2.93	-0.00
3.00	356.92	47.84	-0.00	-2.29	2.80	-0.00
3.25	356.42	48.48	-0.00	-1.93	2.49	-0.00
3.50	356.13	48.94	-0.00	-1.39	1.98	-0.00
3.75	356.03	49.16	.10	-0.65	1.23	-0.00
4.00	356.28	49.66	.00	.27	.39	-0.00
4.25	356.90	49.58	.00	2.97	-2.60	-0.00
4.50	357.03	47.74	.00	3.93	-3.99	-0.00
4.75	358.96	46.56	.00	4.65	-2.31	-0.00
5.00	360.21	45.87	.00	5.13	-0.56	-0.00
5.25	361.49	43.29	.00	5.36	-7.73	-0.00
5.50	362.71	41.25	.00	5.35	-8.88	-0.00
5.75	363.77	38.98	.00	5.09	-9.00	-0.00
6.00	364.59	36.50	.00	4.59	-10.85	-0.00
6.25	365.09	33.45	-0.00	1.44	-10.85	-0.00
6.50	365.29	31.85	-0.00	.44	-11.31	-0.00
6.75	365.26	28.15	-0.00	-0.47	-11.66	-0.00
7.00	365.03	25.19	-0.00	-1.26	-11.94	-0.00
7.25	364.65	22.21	-0.00	-1.92	-12.13	-0.00
7.50	364.16	19.25	-0.00	-2.46	-12.86	-0.00
7.75	363.62	16.36	-0.00	-2.97	-11.90	-0.00
8.00	363.07	13.56	-0.00	-3.15	-11.73	-0.00
8.25	362.56	10.93	.01	-1.98	-10.22	.01
8.50	362.08	8.42	.00	-1.32	-9.41	.01
8.75	361.65	6.16	.00	-1.67	-8.50	.01
9.00	361.26	4.15	.01	-1.47	-7.58	.01
9.25	360.92	2.42	.01	-1.28	-6.39	.00
9.50	360.62	1.03	.01	-1.10	-5.18	.00
9.75	360.38	-0.01	.01	-.93	-3.88	.00
10.00	360.18	-.64	.01	-.73	-2.48	.00
10.25	360.04	-.86	.00	-.47	-.33	-0.01
10.50	359.95	-.74	.00	-.29	.76	-0.01
10.75	359.91	-.39	.00	-.12	1.58	-0.00
11.00	359.90	.11	-.06	.04	2.14	.00
11.25	359.92	.65	.00	.18	2.44	.01
11.50	359.97	1.14	.04	.30	2.40	.02
11.75	360.05	1.46	.01	.41	2.25	.03
12.00	360.14	1.53	.02	.51	1.75	.04
12.25	360.25	1.27	.04	.37	-1.77	.07
12.50	360.34	.65	.06	.27	-3.19	.07
12.75	360.40	-.32	.08	.12	-4.60	.06
13.00	360.42	-1.65	.09	-.09	-6.02	.05
13.25	360.35	-3.33	.10	-.35	-7.43	.03
13.50	360.28	-5.37	.10	-.67	-8.85	.00
13.75	359.93	-7.75	.09	-1.05	-10.26	.03
14.00	359.51	-10.50	.06	-1.49	-11.68	.07
14.25	358.95	-13.58	.12	-2.38	-12.73	.17
14.50	358.29	-16.91	-.03	-2.66	-13.45	.19
14.75	357.57	-20.40	-.08	-2.81	-13.94	.20
15.00	356.85	-24.95	-.13	-2.80	-14.16	.10
15.25	356.19	-27.45	-.17	-2.66	-14.12	.14
15.50	355.63	-30.81	-.19	-2.38	-13.61	.09

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

15.75	353.23	-33.93	-1.18	-1.96	-13.24	-1.82
16.00	355.54	-35.71	-1.14	-1.94	-12.11	-1.68
16.25	355.10	-39.06	-1.06	.82	-9.06	.63
16.50	355.38	-41.01	.13	1.39	-7.12	1.20
16.75	355.84	-42.58	.98	2.05	-5.67	1.93
17.00	356.43	-43.42	1.85	2.59	-4.31	2.82
17.25	357.12	-44.75	1.91	3.32	-3.03	3.88
17.50	357.85	-45.40	3.12	3.93	-1.85	5.10
17.75	358.63	-45.82	4.73	3.93	-1.72	5.69
18.00	359.31	-46.02	5.81	3.62	.25	6.64
18.25	359.94	-46.06	5.95	2.97	.11	8.08
18.50	360.49	-45.95	12.02	2.25	.59	9.35
18.75	360.96	-45.73	14.42	1.71	.99	10.75
19.00	361.35	-45.43	16.16	1.37	1.31	12.08
19.25	361.65	-45.03	16.83	1.03	1.54	13.36
19.50	361.06	-44.73	16.04	.68	1.63	14.44
19.75	361.59	-44.38	13.38	.33	1.75	15.29
20.00	362.02	-44.08	8.7	-.02	1.73	16.21
20.25	361.96	-43.85	1.12	-.36	.79	17.39
20.50	361.82	-43.69	-7.08	-.61	.54	18.31
20.75	361.61	-43.59	-17.53	-.82	.32	19.59
21.00	361.41	-43.54	-26.84	-.97	.12	20.28
21.25	361.15	-43.55	-34.80	-1.39	-.05	21.13
21.50	360.95	-43.55	-40.70	-1.14	-.20	22.38
21.75	360.66	-43.55	-42.54	-1.15	-.32	23.96
22.00	360.46	-43.64	-40.52	-1.12	-.42	25.87
22.25	360.31	-43.69	-33.41	-.98	-.28	28.19
22.50	360.24	-43.74	-22.13	-.77	-.17	30.66
22.75	360.31	-43.76	-7.08	-.62	-.12	33.93
23.00	360.53	-43.81	8.14	1.27	-.05	38.01
23.25	360.95	-43.86	24.73	2.02	.04	42.98
23.50	361.61	-43.77	44.69	2.67	.14	48.59
23.75	362.55	-43.71	54.83	3.81	.26	54.68
24.00	363.79	-43.66	65.94	4.85	.39	62.36
24.25	365.37	-43.44	73.15	5.86	.73	72.56
24.50	367.25	-43.24	76.79	7.95	.94	84.85
24.75	369.39	-42.97	77.52	8.92	1.16	98.71
25.00	371.74	-42.66	76.81	9.77	1.36	113.73
25.25	374.25	-42.28	72.87	19.50	1.61	129.80
25.50	376.89	-41.65	68.81	11.11	1.84	147.52
25.75	379.61	-41.35	64.46	11.61	2.08	166.29
26.00	382.37	-41.79	61.47	11.97	2.33	186.31
26.25	385.11	-41.16	57.38	10.93	2.63	207.87
26.50	387.84	-39.47	55.14	10.42	2.89	230.46
26.75	390.53	-39.72	53.52	10.68	3.11	254.23
27.00	393.18	-37.91	52.83	10.52	3.33	279.36
27.25	395.79	-37.05	52.53	10.34	3.54	305.81
27.50	398.33	-36.15	51.86	11.13	3.74	333.62
27.75	400.81	-35.20	51.55	9.89	3.93	362.85
28.00	403.21	-34.21	51.95	9.63	4.11	393.53
28.25	405.53	-33.19	51.33	9.89	4.33	425.83
28.50	407.76	-32.13	49.51	8.76	4.56	459.52
28.75	409.50	-31.05	48.53	8.44	4.78	494.68
29.00	411.97	-29.95	47.44	8.13	4.99	531.51
29.25	413.97	-29.83	46.39	7.82	5.21	569.81
29.50	415.89	-27.71	45.13	7.52	5.45	609.98
29.75	417.74	-26.58	44.01	7.23	5.69	652.02

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

31.53	419.53	-25.45	42.97	6.95	4.61	-4.93
31.25	421.25	-25.33	42.07	6.75	4.48	-3.42
31.51	422.91	-23.21	41.28	6.49	4.37	-2.96
31.75	424.50	-22.13	40.59	6.22	4.26	-2.59
31.60	426.02	-20.98	39.99	5.96	4.15	-2.24
31.25	427.47	-19.87	39.47	5.69	4.05	-1.94
31.50	428.86	-18.75	38.99	5.41	3.96	-1.67
31.75	431.17	-17.63	38.56	5.14	3.87	-1.46
32.00	432.42	-16.50	38.15	4.86	3.78	-1.26

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

5.000	5122500E+04	-1.0791076E+03	.18553566E+02	.9305753E+01
	4.113337E+02	-.82395935E+02	-.01790307E+01	.14112146E+01
	-.8666874E+03	-.10621922E+03	-.15241595E+02	.05923638E+00
6.000	4.9541617E+04	-.14801140E+03	.21342239E+02	-.31490073E+00
	4.9061124E+02	-.94519582E+02	-.39452169E+01	.19311048E+01
	-.80940916E+03	-.11341250E+03	-.12666186E+02	.15251847E+01
7.000	4.4271048E+04	-.10626640E+03	.20403335E+02	-.12377506E+01
	4.1562382E+03	-.96706732E+02	.17580974E+01	.12391467E+01
	-.93475324E+03	-.15427000E+03	-.80080714E+01	.18898543E+01
8.000	4.7464762E+04	-.69179824E+02	.16687051E+02	-.8267974E+01
	4.29333428E+03	-.89476067E+02	.54725374E+01	.46731242E+01
	-.11167121E+04	-.16803161E+03	-.50646706E+01	.94425711E+00
9.000	4.6852574E+04	-.42735281E+02	.97666807E+01	-.2224516E+01
	4.32207849E+03	-.77129055E+02	.59744747E+01	-.13623051E+01
	-.12888043E+04	-.17532079E+03	-.22325872E+01	.68235490E+00
10.000	4.6499503E+04	-.30045451E+02	.30331400E+01	.74158534E+00
	4.39448738E+03	-.57467020E+02	.27875598E+01	.45410165E+00
	-.14658233E+04	-.17790672E+03	-.42544235E+00	-.28076493E+00

INTERPOLATED TRAJECTORY DATA LINEAR UNITS FROM INPUT, ANGLES IN DEGREES

TIME	X	Y	Z	XDOT	YDOT	ZDOT	PSIT	THETAT	LAT	ACCIG
6.000	6300.600	280.030	-500.000	-250.336	2.833	3.251	179.337	-0.744	1.890	
6.250	6239.250	281.474	-499.474	-249.326	.797	.936	179.014	-0.219	1.265	
6.500	6179.767	283.422	-499.524	-249.985	-1.394	-1.378	179.683	.329	1.201	
6.750	6117.914	199.810	-500.167	-264.367	-3.686	-3.749	179.231	.812	1.174	
7.000	6056.615	199.602	-501.398	-288.475	-6.089	-6.117	178.793	.947		
7.250	5991.644	196.938	-503.088	-289.377	-7.791	-7.931	178.319	1.237	1.452	
7.500	5919.047	194.826	-505.245	-249.163	-9.931	-10.636	177.704	2.056	1.879	
7.750	5859.644	192.113	-508.161	-239.832	-12.666	-14.052	177.077	3.349	2.171	
8.000	5800.852	188.613	-512.093	-237.386	-15.819	-18.121	176.188	4.956	2.866	
8.250	5748.663	184.144	-517.283	-241.854	-23.416	-23.634	175.175	5.573	2.884	
8.500	5679.357	178.528	-523.864	-244.009	-25.483	-29.531	174.339	6.863	3.156	
8.750	5617.786	171.593	-531.942	-243.971	-31.137	-35.663	172.751	8.251	3.709	
9.000	5556.803	163.130	-541.625	-241.618	-37.873	-42.888	171.277	9.767	4.352	
9.250	5497.120	159.026	-553.020	-239.937	-43.619	-49.413	169.921	11.643	4.497	
9.500	5438.887	151.285	-566.250	-235.819	-50.122	-57.073	167.839	13.638	4.643	
9.750	5382.113	137.962	-581.435	-224.151	-56.283	-65.059	165.935	15.722	4.787	
10.000	5326.816	113.118	-598.698	-218.279	-62.403	-73.372	164.363	17.910	4.927	
4.500	5226.961	79.738	-618.129	-211.529	-67.856	-81.830	162.215	20.233	5.016	
4.750	5174.691	61.172	-639.687	-204.218	-73.433	-90.190	160.323	22.588	5.066	
5.000	5122.500	44.133	-663.296	-196.355	-77.852	-98.333	158.371	24.958	5.084	
5.250	5076.785	28.115	-688.687	-187.911	-82.396	-106.219	156.323	27.372	5.030	
5.500	5033.366	13.003	-716.331	-178.235	-85.956	-113.518	154.250	29.836	5.012	
5.750	4992.444	-2.963	-745.704	-168.437	-89.153	-120.812	152.184	32.327	5.018	
6.000	4954.162	-12.088	-776.753	-158.316	-92.818	-127.471	149.937	34.963	5.026	
6.250	4918.488	-22.068	-809.489	-146.612	-94.820	-134.125	147.439	37.372	5.033	
6.500	4885.473	-32.907	-843.788	-134.457	-96.579	-139.885	145.132	39.860	5.057	
6.750	4855.027	-43.869	-879.527	-122.902	-98.564	-145.264	142.743	42.321	5.080	
7.000	4827.180	-54.864	-916.563	-116.511	-96.873	-150.262	140.275	44.751	5.096	
7.250	4811.869	-65.871	-954.753	-106.266	-96.717	-154.878	137.637	47.147	5.096	
			-993.963	-96.536	-95.363	-158.544	135.343	49.441	5.171	

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

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7.563	4770.662	-193.303	-1034.008	-87.114	-93.713	-151.959	-132.987	51.693	3.904
7.751	4758.433	-216.643	-1075.036	-77.937	-91.768	-165.121	-130.353	53.699	3.886
8.009	4740.071	-239.334	-1116.712	-69.179	-89.876	-168.032	-127.718	56.096	3.861
8.250	4723.788	-261.354	-1159.042	-61.728	-86.553	-173.216	-125.493	58.312	3.817
8.587	4719.366	-282.666	-1201.076	-54.819	-83.836	-172.132	-123.274	59.889	2.999
8.781	4696.597	-303.166	-1245.166	-48.511	-80.391	-173.859	-121.103	61.628	2.691
9.008	4685.257	-322.670	-1288.864	-42.785	-77.129	-175.329	-119.013	63.299	2.888
9.251	4675.133	-341.744	-1332.827	-36.766	-74.283	-176.219	-117.584	64.588	2.018
9.560	4666.013	-359.897	-1377.412	-30.845	-71.617	-176.959	-116.241	65.715	1.618
9.781	4657.691	-377.425	-1421.363	-25.333	-69.372	-177.548	-115.032	66.873	1.216
10.063	4649.954	-394.457	-1465.823	-20.045	-67.457	-177.987	-114.883	67.664	.817
10.251	4642.664	-411.173	-1510.353	-15.051	-65.983	-178.275	-113.284	68.091	.954
10.503	4635.793	-427.467	-1554.968	-10.251	-64.225	-178.613	-112.247	68.769	1.091
10.750	4629.435	-443.328	-1599.637	-6.412	-62.834	-179.031	-111.111	69.387	1.238
11.006	4623.603	-459.713	-1644.436	-21.755	-60.530	-179.440	-109.759	70.280	1.369

EULER ANGLES AND ANGLE OF ATTACK (DEG)

TIME	PSI	THETA	PHI	ALFA
0.00	179.37	2.68	21.13	3.02
1.00	181.17	3.12	23.64	2.87
2.00	183.46	9.17	25.92	5.35
3.00	187.74	16.13	38.33	8.04
4.00	193.76	26.18	33.55	9.80
5.00	200.49	36.38	35.38	10.73
6.00	209.01	46.87	38.18	11.59
7.00	220.08	56.34	39.17	11.18
8.00	233.09	64.61	39.46	10.11
9.00	242.81	76.17	29.78	7.62
10.00	246.84	78.67	19.17	3.37
11.00	254.95	74.68	33.49	4.96

SPLINE INTERPOLATION COEFFICIENTS

6.006	.3138594E+01	.26921150E-01	.17436061E-02	.26951111E-02
	.3523194E-01	-.25459689E-01	.24386161E-01	.19294422E-01
	.36805758E+00	.24643623E-01	.36689923E-01	-.26129322E-01
1.000	.31619298E+01	.38236952E-01	-.39529086E-02	.11296914E-01
	.54452884E-01	.61195899E-01	.61671477E-01	-.17285312E-01
	.60206201E+00	.13635701E-01	-.54515095E-01	.91285817E-01
2.000	.32010966E+01	.53007422E-01	.24336352E-01	-.26025062E-02
	.16003494E+00	.11268291E+00	-.10184471E-01	.18999118E-01
	.45238763E+00	.17822136E+00	.21910158E+00	-.18771643E+00
3.000	.32766381E+01	.93073173E-01	.16529117E-01	-.53004569E-02
	.23148280E+01	.14916222E+00	.6663783E-01	-.20317812E-01
	.66899412E+00	.74275186E-01	-.32394775E+00	.16539163E+00

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

4.000	.3361739E+01	.1110300E+00	.6277457E-03	.5730131E-02
	.4569317E+00	.1015307E+00	-.1128726E-01	.3291242E-02
	.5356132E+00	-.7564593E-01	.1731266E+00	-.6559516E-01
5.000	.3499127E+01	.1294759E+00	.1781814E-01	.1479367E-02
	.6335245E+00	.1804079E+00	.1355847E-01	-.9814372E-02
	.6174905E+00	.7392176E-01	-.2365989E-01	-.1227943E-02
6.000	.3647492E+01	.1695200E+00	.2223598E-01	.1324539E-02
	.6180045E+00	.1745078E+00	-.1585564E-01	.2554755E-02
	.6664334E+00	.2282164E-01	-.2734272E-01	.1933164E-01
7.000	.3441173E+01	.2105606E+00	.2604662E-01	-.1846347E-01
	.9322956E+00	.1564590E+00	-.8192495E-02	-.1971656E-02
	.6918423E+00	.2792904E-01	.3245160E-01	-.2354951E-01
8.000	.4368133E+01	.2169536E+00	-.2341167E-01	-.1882234E-01
	.1127655E+01	.1323895E+00	-.1389724E-01	-.2137159E-01
	.6886734E+00	-.5761629E-01	-.1281969E+00	.2564745E-01
9.000	.6237852E+01	.1036614E+00	-.8490511E-01	.5161408E-01
	.1224756E+01	.4044829E+00	-.7831203E-01	.4625544E-01
	.5163477E+00	-.2472678E+00	-.5125057E-01	.1148629E+00
10.000	.4308247E+01	.6674704E-01	.6356173E-01	-.1724693E-01
	.1233460E+01	.2220256E-01	.6175430E-01	-.1541843E-01
	.3346482E+00	-.5188157E-02	.2933342E+00	-.1820764E-01

INTERPOLATED TRAJECTORY DATA (LINEAR UNITS FROM INPUT, ANGLES IN DEGREES)

TIME	PSIT	THE1	PHIT	PSI10	THE10	PHI10
4.00	179.37	2.08	21.13	1.54	-1.46	1.41
4.25	179.77	1.82	21.59	1.65	-.35	1.06
4.50	180.19	1.63	22.16	1.79	1.04	1.90
4.75	180.65	2.23	22.70	1.97	2.71	1.54
5.00	181.17	3.12	23.04	2.14	4.65	.78
5.25	181.69	4.42	23.12	2.16	5.47	1.18
5.50	182.20	5.92	23.36	2.29	6.05	2.68
5.75	182.77	7.53	24.07	2.54	6.38	5.89
6.00	183.46	9.17	25.92	3.04	6.46	10.21
6.25	184.38	10.76	29.10	3.68	6.57	12.61
6.50	185.30	12.39	32.87	4.28	6.96	12.41
6.75	186.45	14.14	36.27	4.45	7.62	9.63
7.00	187.74	16.13	38.33	5.38	9.55	4.26
7.25	189.14	18.41	38.39	5.74	9.45	-1.45
7.50	190.63	20.92	37.02	6.02	10.06	-4.78
7.75	192.18	23.55	35.11	6.23	10.37	-5.74
8.00	193.76	25.18	33.55	6.36	10.49	-4.39
8.25	195.36	26.74	33.03	6.50	10.19	-.78
8.50	196.99	31.25	33.40	6.73	10.11	1.83
8.75	198.69	33.75	34.30	7.13	10.17	3.51
9.00	200.49	36.34	35.38	7.42	10.36	4.23
9.25	202.40	38.93	36.35	7.96	11.54	3.53
9.50	204.46	41.60	37.15	8.52	10.57	-2.88
9.75	206.66	44.27	37.76	9.11	10.47	2.86
10.00	209.61	46.87	38.18	9.71	10.23	1.31
10.25	211.52	49.38	38.43	10.38	9.83	.95

TRAJECTORY GENERATION BY PIECEWISE S-LINE INTERPOLATION

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6.50	214.19	51.78	38.59	11.07	9.07	.88
6.75	217.05	54.69	38.77	11.79	9.84	1.10
7.00	220.60	56.34	39.07	12.52	6.85	1.66
7.25	223.29	58.52	39.54	12.94	6.57	1.38
7.50	226.60	60.63	39.95	13.93	8.27	.39
7.75	229.89	62.67	40.12	12.85	7.94	-1.36
8.00	233.09	64.61	39.66	12.43	7.54	-3.09
8.25	236.08	66.44	38.85	11.21	6.73	-7.01
8.50	238.76	68.05	35.86	9.72	5.50	-9.76
8.75	241.04	69.33	33.83	7.97	4.69	-12.15
9.00	242.81	70.17	29.70	5.94	2.32	-14.17
9.25	244.04	70.51	26.07	4.62	1.53	-15.17
9.50	244.93	70.55	22.76	4.83	.54	-15.52
9.75	245.78	71.52	20.20	4.19	.54	-6.23
10.00	246.84	70.67	19.17	5.08	1.33	-.30
10.25	248.35	71.21	26.12	6.72	2.74	7.28
10.50	250.27	72.10	22.95	8.11	3.43	14.32
10.75	252.50	73.25	27.48	9.25	4.59	23.80
11.00	254.95	74.66	33.49	10.14	5.84	26.76

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

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OPTION 3. TRAJECTORY SPECIFIED BY FLIGHT PATH ANGULAR POSITION.
 HORIZONTAL SPIRAL MANEUVER.
 DIMENSIONS IN FEET AND FT/SEC

TRAJECTORY NO. = 2 OPTION NO. = 3 NO. OF BREAKPOINTS = 10

(DCL/DAL)1 ALFA1 EULER ANGLE INTERPOLATION SELECTED RHOSL MNORM SL GRAVITY
 2.000 15.000 .750 86.000 .00000 1.00000 32.17

OUTPUT FRAME TRANSFORMATION PSI(DEG) PSI(DEG)
 Z0 43C.00 25.00 0.00 0.00

INPUT TABLES

TIME	X COMP	Y COMP	Z COMP
0.000	0.000	0.000	0.000
1.000	0.000	0.000	0.000
2.000	0.000	0.000	0.000
3.000	0.000	0.000	0.000
4.000	0.000	0.000	0.000
5.000	0.000	0.000	0.000
6.000	0.000	0.000	0.000
7.000	0.000	0.000	0.000
8.000	0.000	0.000	0.000
9.000	0.000	0.000	0.000

SPLINE INTERPOLATION COEFFICIENTS

0.000	.13035926E+05	.6944047E+03	-.97302845E+02	.13998245E+03
1.000	-.58861200E+04	-.36138339E+03	.88482643E+02	-.56741494E+02
2.000	-.24000000E+04	-.17006164E+02	.1952936E+02	-.26867722E+01
3.000	.14512046E+05	.8208213E+03	-.18244656E+03	.8453714E+02
4.000	-.62157623E+04	-.3546259E+03	.9557935E+02	-.70986124E+01
5.000	-.24000000E+04	.14319391E+02	.44729235E+01	.15220312E+02
6.000	.15243925E+05	.7172015E+03	.71104591E+02	-.28597593E+02
7.000	-.64019222E+04	-.18477412E+03	.74289018E+02	-.23773507E+02
8.000	-.23659077E+04	.68925275E+02	.58132966E+02	-.17299995E+02
9.000	.15004262E+05	.7738664E+03	-.14518205E+02	.5892621E+00
10.000	-.65161862E+04	-.10753274E+03	.29523581E+01	-.29418732E+02
11.000	-.22642094E+04	.11735120E+03	-.17070365E+01	-.13726994E+02
12.000	.16764646E+05	.74687691E+03	-.12991427E+02	-.53867443E+01
13.000	-.67501754E+04	-.18085431E+03	.85273927E+02	.11262592E+02
14.000	-.21622922E+04	.7275647E+02	-.42887716E+02	.46407725E+01
15.000	.17493136E+05	.70473378E+03	-.29151701E+02	-.99179971E+01
16.000	-.73140173E+04	-.2654336E+03	-.51415121E+02	-.4263045E+01
17.000	-.21277694E+04	.9432435E+00	-.29925406E+02	-.44778445E+01

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

6.000	.13159022E+05	.51967610E+03	-.55905741E+02	.10711684E+02
	.73962361E+04	-.46215452E+03	-.54196835E+02	.21368317E+02
	-.21682286E+04	-.70330676E+02	-.42356633E+02	.14152433E+02
7.000	.11742284E+05	.56399975E+03	.22931159E+02	.1757140E+02
	-.18612201E+04	-.50644703E+03	-.95483835E+01	.22616194E+02
	.37717E+04	-.11259479E+03	.13072447E+02	.146101027E+02
8.000	.13323772E+05	.61562802E+03	.51430755E+02	-.50857163E+01
	.61651480E+04	-.43879530E+03	.57748215E+02	-.75395998E+01
	-.23570047E+04	-.6905057E+02	.62643634E+02	-.47275060E+01

INTERPOLATED TRAJECTORY DATA LINEAR UNITS FROM INPUT, ANGLES IN DEGREES

TIME	X	Y	Z	XDOT	YDOT	ZDOT	PSIT	THETAT	LAT	ACC(5)
0.000	13805.926	1885.120	-2433.036	698.844	-361.393	-17.306	-27.479	1.246	2.324	
0.250	13975.238	-1971.822	-2433.063	687.132	-361.420	-9.167	-26.221	.511	2.394	
.500	14142.616	-6451.784	-2433.916	706.320	-329.642	5.436	-25.483	0.892	2.182	
.750	14318.365	-8131.324	-2432.811	754.233	-335.353	7.436	-23.953	-.521	1.726	
1.000	14512.848	-8215.762	-2408.680	828.982	-354.843	14.319	-22.181	-.910	1.112	
1.250	14710.110	-8298.560	-2395.900	769.453	-303.514	22.253	-21.912	-1.538	2.736	
1.500	14932.293	-6371.076	-2309.821	731.379	-266.133	36.012	-20.235	-2.503	4.234	
1.750	15067.623	-6331.975	-2330.323	713.832	-224.581	49.566	-17.467	-3.790	5.458	
2.000	15243.925	-6081.922	-2365.980	717.721	-186.774	59.925	-16.437	-5.313	5.247	
2.250	15421.360	-6221.844	-2345.893	742.650	-158.517	97.512	-14.984	-6.578	4.552	
2.500	15610.111	-6359.709	-2321.152	769.337	-134.254	114.778	-13.214	-7.509	2.931	
2.750	15814.201	-6588.747	-2293.384	776.933	-117.926	114.725	-8.897	-9.152	1.496	
3.000	16016.262	-6818.186	-2264.209	776.397	-107.533	117.351	-7.985	-8.536	.066	
3.250	16196.460	-6843.344	-2235.193	767.318	-117.082	114.350	-4.675	-8.164	1.456	
3.500	16327.890	-6072.691	-2207.670	750.377	-133.989	111.917	-3.984	-7.520	2.979	
3.750	16577.151	-6707.582	-2182.947	753.563	-158.200	89.153	-11.861	-6.597	4.494	
4.000	16764.640	-6750.175	-2162.292	746.877	-189.834	72.734	-18.282	-5.393	5.984	
4.250	16958.463	-6902.752	-2146.711	738.351	-224.259	53.256	-17.179	-3.927	5.466	
4.500	17194.157	-8365.810	-2136.054	720.499	-261.842	36.523	-19.983	-2.521	4.975	
4.750	17315.217	-8335.771	-2129.480	717.291	-296.613	27.151	-22.483	-1.266	4.512	
5.000	17493.138	-7118.017	-2127.749	704.734	-326.543	.943	-20.851	-.870	3.001	
5.250	17667.360	-7198.933	-2129.411	686.814	-353.849	-15.198	-27.258	1.127	4.514	
5.500	17837.113	-7191.675	-2135.189	666.694	-382.319	-32.459	-28.527	2.419	4.965	
5.750	18001.529	-7289.673	-2145.221	644.235	-411.654	-50.839	-30.575	3.864	5.431	
6.000	18153.662	-7393.236	-2168.229	619.676	-442.155	-73.339	-35.515	5.279	5.986	
6.250	18311.520	-7511.453	-2180.440	590.740	-468.240	-96.210	-37.933	8.481	6.433	
6.500	18458.063	-7630.092	-2214.218	582.492	-484.941	-113.595	-39.543	7.888	2.950	
6.750	18621.066	-7755.948	-2216.838	570.912	-498.386	-107.338	-41.022	8.362	1.469	
7.000	18742.284	-7881.220	-2258.772	564.031	-505.447	-117.227	-41.113	8.449	.510	
7.250	18863.565	-8107.485	-2286.693	570.511	-483.929	-98.313	-39.778	6.059	1.471	
7.500	19026.474	-8131.641	-2313.271	581.286	-464.199	-85.854	-37.893	6.402	2.947	
7.750	19172.605	-8251.569	-2337.179	596.326	-448.795	-69.850	-35.481	5.273	5.915	
8.000	19323.571	-8365.149	-2357.085	615.632	-430.795	-50.311	-32.514	3.796	5.418	
8.250	19480.612	-8473.731	-2371.956	639.149	-407.778	-31.933	-29.793	2.487	4.988	
8.500	19643.325	-8563.552	-2381.940	661.375	-374.585	-17.748	-27.251	1.111	4.301	
8.750	19811.817	-8659.317	-2387.480	612.177	-351.387	1.256	-24.923	-.093	3.873	
9.000	19986.916	-8743.734	-2386.118	701.370	-325.914					

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

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EULER ANGLES AND ANGLE OF ATTACK(DEG)						
TIME	PSI	THETA	PHI	ALFA		
0.00	333.95	1.06	-88.42	-6.99		
1.00	337.24	.41	62.61	2.87		
2.00	346.62	-14.38	-77.60	-33.37		
3.00	352.56	-5.38	3.42	3.16		
4.00	345.75	14.05	-27.51	34.48		
5.00	332.47	16.05	-51.81	16.83		
6.00	307.95	23.75	-63.26	35.18		
7.00	217.00	11.89	.33	3.44		
8.00	332.08	-8.36	-72.12	-27.90		
9.00	337.06	-2.73	-77.72	-12.21		
SPLINE INTERPOLATION COEFFICIENTS						
0.000	.58284907E+01	.45144798E+07	.23681246E+01	.29343396E+01		
	.18486086E+01	.21145898E+00	-.27403379E+01	-.55133153E+01		
	-.15431742E+01	.51700810E+01	-.13164264E+01	-.12823745E+01		
1.000	.58666297E+01	.13998874E+00	.41757544E+01	-.18876390E+01		
	.7191956E+02	-.22943694E+00	-.19877407E+00	.17137369E+01		
	.10927228E+01	-.11315443E+01	-.4269265E+01	.31899999E+01		
2.000	.61496176E+01	.16919203E+00	-.12471550E+01	-.52941425E+01		
	-.24566116E+00	-.11287380E+00	.31533801E+00	-.4688290E+01		
	-.13557481E+01	-.65539794E+00	.45938733E+01	-.28321885E+01		
3.000	.61533975E+01	-.14574540E+01	-.17129582E+00	.67361563E+01		
	-.94884442E+01	.37773615E+00	.17527314E+00	-.21102847E+01		
	.5375965E+01	.65424586E+00	-.35934387E+01	.15055974E+01		
4.000	.60345886E+01	-.15598188E+00	.29880566E+01	-.18276130E+00		
	.24529388E+00	.05799823E+01	-.46621227E+00	.3898149E+00		
	-.10837686E+01	-.98564415E+00	.23335415E+01	-.18632523E+01		
5.000	.58027471E+01	-.41344986E+01	-.28735033E+00	.27577924E+00		
	.17546663E+00	.03118932E+01	.42533212E+00	-.3065332E+00		
	.93912329E+00	-.28317280E+01	-.11562146E+01	.18195944E+01		
6.000	.53747205E+01	-.16982430E+00	.32894152E+00	-.18915613E+01		
	.41458140E+00	.08574429E+01	-.45707874E+00	.16145491E+00		
	-.11348988E+01	.71794677E+00	.19824786E+01	.15111167E+01		
7.000	.52467168E+01	.32465625E+00	-.36588891E+01	-.25888832E+01		
	.28753808E+00	-.34121432E+00	.2728798E+01	.47712892E+01		
	.52179511E+02	-.10446856E+01	-.26388715E+01	.13774116E+01		
8.000	.58897315E+01	.17641267E+00	-.1117469E+00	.8381999E+02		
	-.28680167E+01	-.14358287E+00	.17642827E+00	-.1594831E+01		
	-.12588888E+01	-.11399562E+01	.15813833E+01	-.45943728E+00		

TRAJECTORY GENERATION BY PIECEWISE SPLINE INTERPOLATION

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INTERPOLATED TRAJECTORY DATA: LINEAR UNITS FROM INPUT, ANGLES IN DEGREES									
TIME	PSIT	THET	PMIT	PSIT	THET	PMIT	THET	PMIT	THET
0.00	333.95	1.06	-68.42	1.26	5.39	296.68	296.68	296.68	296.68
0.25	334.12	2.47	-20.86	1.57	3.55	232.63	232.63	232.63	232.63
0.50	334.63	3.58	32.28	3.58	6.21	151.83	151.83	151.83	151.83
0.75	335.61	2.66	62.13	5.45	13.15	64.83	64.83	64.83	64.83
1.00	337.24	4.1	62.61	8.02	15.16	-124.83	-124.83	-124.83	-124.83
1.25	339.38	3.43	33.33	8.62	-14.72	-143.29	-143.29	-143.29	-143.29
1.50	341.72	-7.78	-18.95	9.37	-11.62	-111.19	-111.19	-111.19	-111.19
1.75	344.17	-11.71	-53.52	9.66	-6.49	37.49	37.49	37.49	37.49
2.00	346.62	-14.36	-77.58	8.21	1.56	42.06	42.06	42.06	42.06
2.25	348.95	-16.83	-72.04	5.95	8.93	81.16	81.16	81.16	81.16
2.50	350.91	-13.36	-46.51	2.33	15.62	73.58	73.58	73.58	73.58
2.75	352.21	-10.12	-16.28	2.33	21.64	37.49	37.49	37.49	37.49
3.00	352.56	-5.38	3.62	-4.33	22.07	-25.16	-25.16	-25.16	-25.16
3.25	351.80	4.47	1.61	-6.81	19.43	-68.94	-68.94	-68.94	-68.94
3.50	358.17	5.42	-15.87	-8.35	13.73	-69.85	-69.85	-69.85	-69.85
3.75	364.04	11.33	-38.94	-8.94	4.97	-51.89	-51.89	-51.89	-51.89
4.00	365.76	14.65	-57.51	-10.35	-1.73	-16.43	-16.43	-16.43	-16.43
4.25	363.53	13.31	-64.15	-17.73	-1.04	0.66	0.66	0.66	0.66
4.50	360.96	12.09	-61.94	-23.69	4.76	-1.88	-1.88	-1.88	-1.88
4.75	337.46	10.24	-56.59	-26.06	11.43	-12.84	-12.84	-12.84	-12.84
5.00	332.47	10.35	-53.81	-24.52	13.73	-9.45	-9.45	-9.45	-9.45
5.25	325.77	12.63	-57.44	-19.08	11.58	8.54	8.54	8.54	8.54
5.50	318.47	16.86	-63.88	-9.73	5.67	41.14	41.14	41.14	41.14
5.75	312.64	21.12	-67.54	1.42	-4.55	53.17	53.17	53.17	53.17
6.00	307.95	23.75	-63.26	15.53	-11.86	63.90	63.90	63.90	63.90
6.25	307.25	23.53	-47.52	18.60	-16.86	42.31	42.31	42.31	42.31
6.50	309.33	20.90	-26.26	17.82	-19.58	-46.37	-46.37	-46.37	-46.37
6.75	313.19	16.73	-7.62	15.87	-15.25	-72.42	-72.42	-72.42	-72.42
7.00	317.80	11.89	-30	12.77	-12.08	-78.73	-78.73	-78.73	-78.73
7.25	322.30	7.14	-8.84	10.11	-8.22	-89.51	-89.51	-89.51	-89.51
7.50	326.48	2.85	-27.82	7.39	-3.68	-32.17	-32.17	-32.17	-32.17
7.75	329.97	-7.74	-51.65	4.18	-0.83	-9.61	-9.61	-9.61	-9.61
8.00	332.98	-3.36	-72.12	1.46	4.72	14.39	14.39	14.39	14.39
8.25	335.81	-4.82	-63.48	-1.26	8.57	27.81	27.81	27.81	27.81
8.50	336.39	-5.15	-66.76						
8.75	337.66	-4.42	-83.61						
9.00	337.06	-2.73	-77.76						

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